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LOWER COST BY SUBSTITUTING STEEL FOR TITANIUM

AF1410 Steel - Detail Design and Development Tests

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June 1977

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This interim report presents the results of a detail design and development test program as Phase II of Contract F33615-75-C-3109. Two selected components of the B-1 structure presently designed as Ti 6AL-4V were redesigned using AF1410 steel taking full advantage of the higher strength and lower volume aspects. Both cost and weight savings are documented to show representative possibilities on similar parts of other aircraft structures. A cost saving of

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22.9 and 22.1 percent and weight saving of 7.6 and 15.1 percent are projected in the two examples designed.

Mechanical properties of AF1410 steel are validated through over 400 development tests run on production heats of this material. Tests covered parent metal properties and weld properties obtained from both static and fatigue tests.

A special pre-machining heat-treatment was developed to permit lower cost machining prior to final heat-treatment for high strength properties. Both heat-treat processes were selected from a series of heat-treat tests conducted.

FOREWORD

This report was prepared by the Los Angeles Aircraft Division of Rockwell International (Rockwell) under contract F33615-75-C-3109 and fulfills the requirement for CDRL Item 0002, Sequence No. A00A. The program is sponsored by the Structures Division of the Air Force Flight Dynamics Laboratory (AFFDL/FBS) at Wright-Patterson Air Force Base, Ohio. The program is under the direction of Mr. George Estill, AFFDL/FBS project engineer.

This is an interim report covering the work accomplished in phase II of the five-phase program. This phase involves detail design and development test and cover the period 1 July 1976 to 1 April 1977. The report was prepared through the combined efforts of the following: W.E. Routh, Program Manager; J.H. Stolpestad, Fatigue and Fracture Mechanics; G.V. Bennett, and R.P. Robelotto, Materials and Producibility Engineering. Major contributors of test data were G.R. Martin, J.F. Harrington, and D. Brubaker, of Materials and Producibility Metallurgy and Fabrication groups.

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Section I

INTRODUCTION

The effort covered by this interim report consists of a 9-month development test program and the detail design and drawing release of the two candidate items selected in phase I.

The development test program has been conducted to obtain design allowable strength and fatigue values of production size heats of AF1410 steel. Also, many tests were conducted to obtain characteristic data on crack propagation for damage tolerance and the effects of various manufacturing processes on the mechanical properties of both parent metal and welds.

Detail design of the candidate test components consisted of refinement of analyses for strength, fatigue and damage tolerance, weight, and cost. Detail drawings have been prepared and released to manufacturing. These consist of die forging drawings and finish-machined parts, where applicable. Although both candidate parts have been released, only one is selected for fabrication and test. The part selected is the wing sweep actuator inboard attach fitting which is a steel substitute part for the corresponding titanium part of the B-1 bomber.

Section II

SUMMARY OF PHASE II ACTIVITY

The development test portion of this phase was started with the receival and preparation of the first shipment of rolled plate AF1410 steel. It was layed out, sectioned into specimen size blocks, and heattreated.

Parent metal material property tests for tension, compression, shear, and bearing values were done. The effects of grinding, shot peening, plating, and welding were determined on tensile values. A series of fatigue and crack growth tests was also conducted on the basic material as well as for manufacturing process effects. A number of dog-bone-type specimens were tested for fracture mechanics analysis verification.

Butt fusion weld data were obtained through K_{1c} Charpy V-notch and fatigue tests. Special specimens were designed for fillet-weld tension across the welds and for fatigue.

Tests were also conducted to develop an optimum final product heat-treatment which is compatible with a premachining heat-treatment selected during phase I, and will develop the required mechanical properties of the material. Machining tests will be conducted on AF1410 material specimens subjected to this heat-treatment during phase III of the program.

Detail design drawings were developed of the two candidate items for component test. All preliminary analyses of stress, fatigue, damage tolerance, weight, and cost were refined and updated to reflect the final designs. Drawings were released to manufacturing for use in preliminary planning and tool design. The wing sweep actuator inboard attach fitting has been selected for fabrication and test.

Tools to be used in machining and heat-treatment of the selected part are designed and will be ready for fabrication during phase III. These include holding fixtures, tracer pattern, heat-treat fixture, and match drill jig for attach holes. A complete manufacturing plan was developed for producing either candidate test part. (Refer to report NA-76-846.)

Section III

OBJECTIVES OF PHASE II - DETAIL DESIGN AND DEVELOPMENT TEST

The planned objectives of this portion of the program are:

1. Prepare specimens and conduct a thorough development test program on representative production heats of AF1410 steel. Tests include mechanical properties of parent metal and of butt and fillet welds. They will also include manufacturing process effects, stress corrosion, and fatigue.

2. Conduct fracture mechanics analysis verification tests to substantiate analytical methods of predicting lifetimes using established growth rates and prescribed flaws.

3. Conduct heat-treat tests to select a heat-treatment which is compatible with premachining heat-treatments selected for easier machining and which will result in the required mechanical properties of the material.

4. Refine the preliminary designs of both candidate parts and update the analyses on each for strength, fatigue, damage tolerance, weight, and cost.

5. Prepare and release to manufacturing detail drawings of each candidate part.

6. Select one of the two candidate parts for fabrication and component test for static and fatigue strength.

7. Design all tools required for machining the selected part from a furnished die forging.

8. Prepare a complete detail design report and submit to the customer, and prepare and present an oral briefing at Wright-Patterson Air Force Base, Ohio, in April 1977.

Section IV

PHASE II DETAIL SCHEDULE AND TASK/EVENT FLOW DIAGRAM

A phase II work plan schedule to accomplish the tasks listed and the objectives given in section III is shown in figure 1 A detail schedule of the tests comprising the development test program is shown in figure 2 This schedule has been used to track the progress of tests on a weekly basis.

A task/event flow diagram is shown in figure 3 which shows the sequence of significant events and their interrelationship. This chart, in conjunction with the sc' d'ule charts, form the tools used in phase II to guide the expenditure of [illegible] n a timely basis.

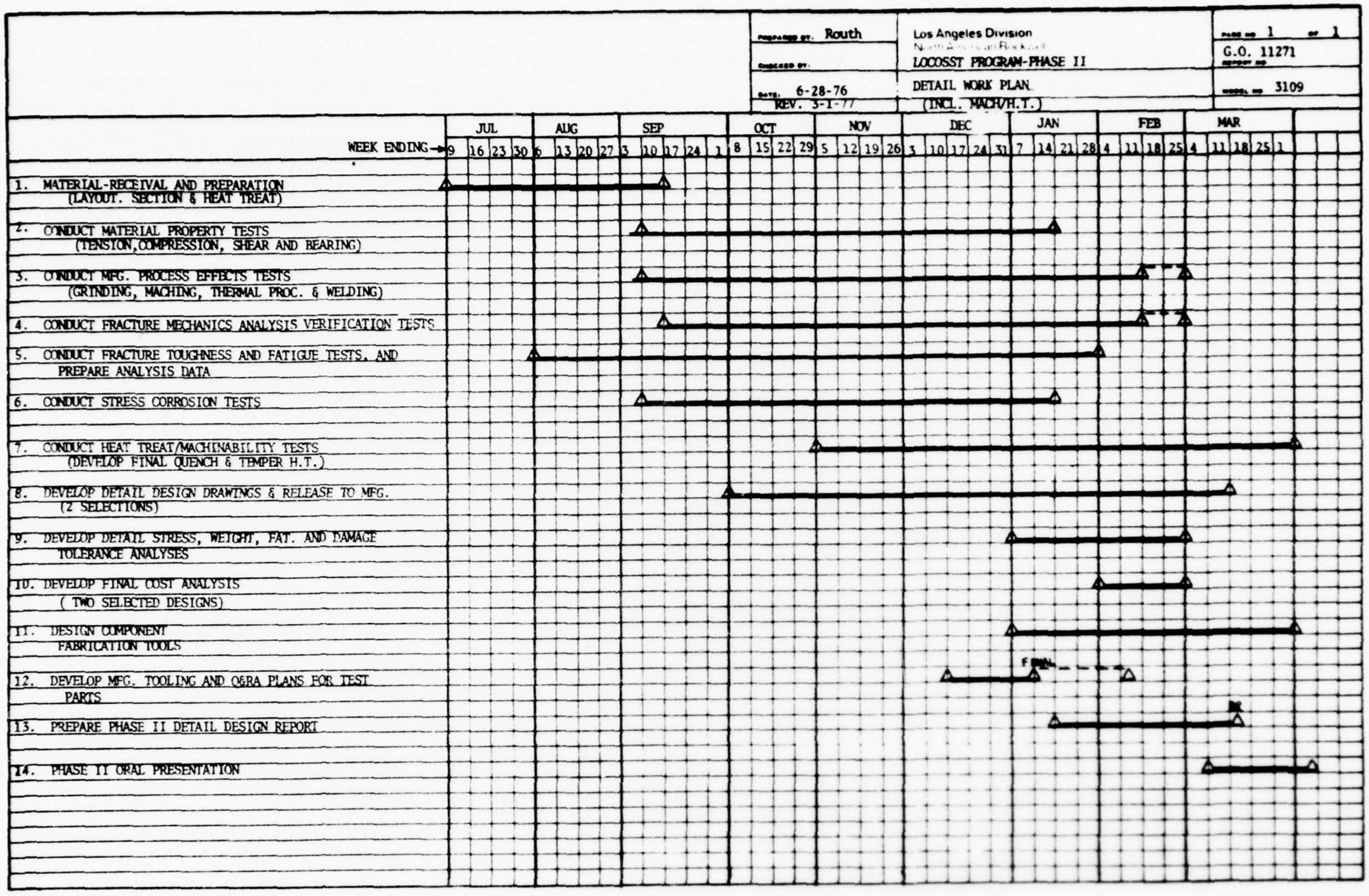


Figure 1 LOCOSST Program - Phase II Detail Work Plan

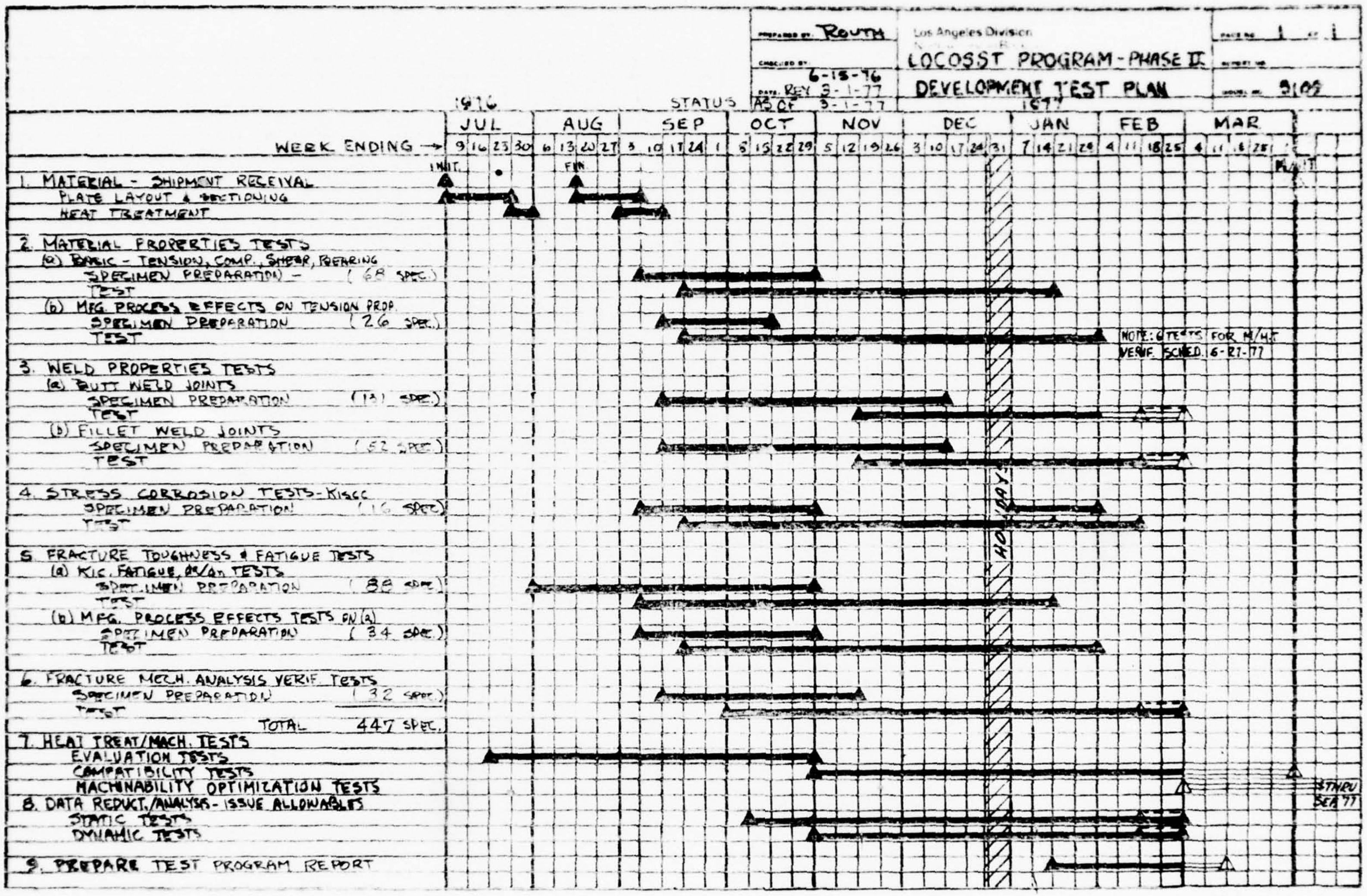


Figure 2 LOCOSST Program - Phase II Development Test Plan

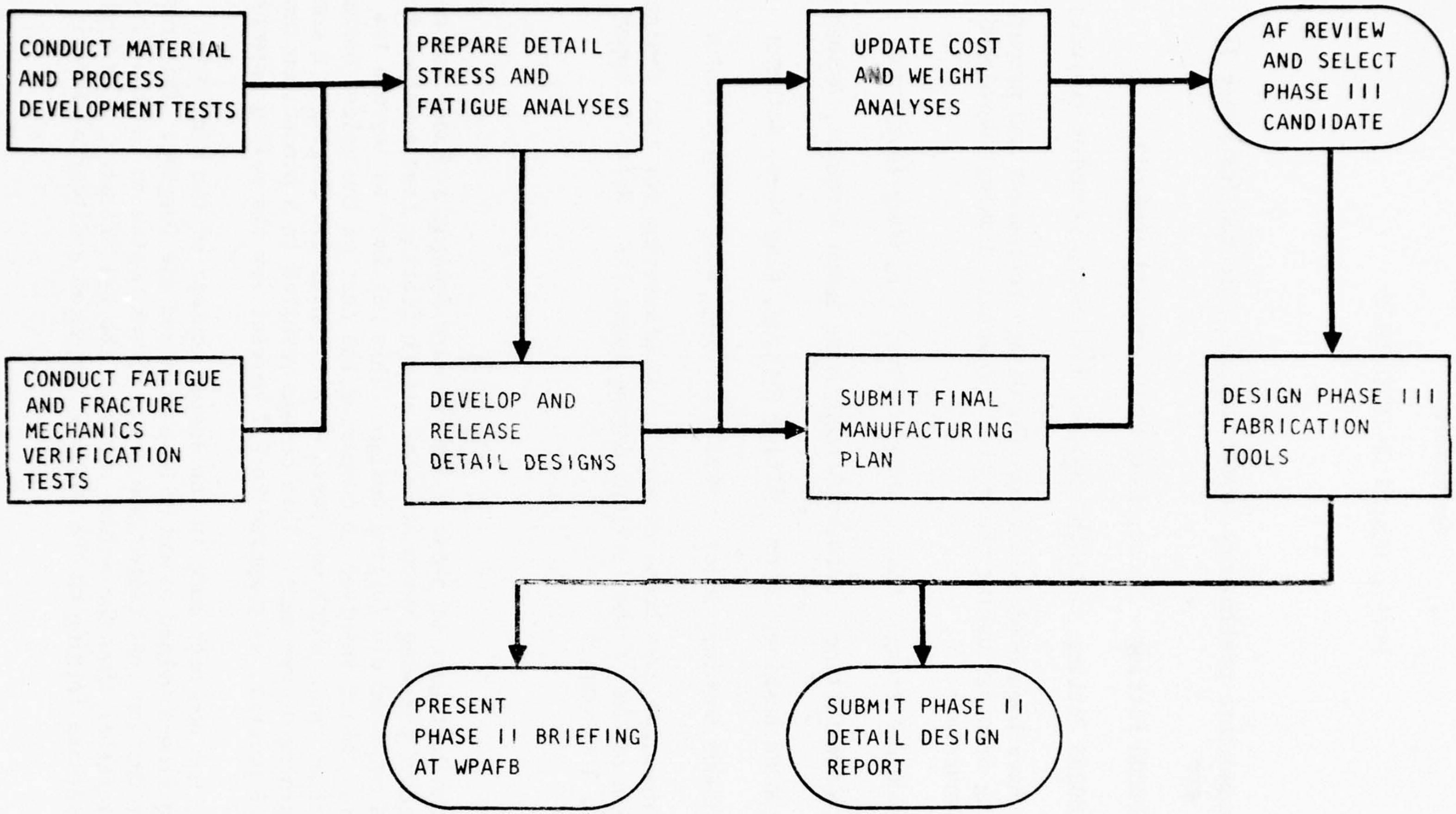


Figure 3 Task/Event Flow Diagram Phase II - Detail Design and Development Test

Section V

DETAIL DESIGN OF CANDIDATES

INTRODUCTION

The two candidate preliminary layout designs selected for phase II detail design are:

- 3109-100000 Fitting - Shear, Wing Pivot Inboard (Layout)
- 3109-100003 Fitting - Attach, Inboard Wing Sweep Actuator (Layout)

These layouts have been used as a basis for design refinement and preparation of working drawings during phase II. The detail drawings developed from these layouts are:

- 3109-100010 Fitting - Shear, Inboard Pivot Pin, Wing (Forging)
- 3109-100006 Fitting - Inboard Attach, Wing Sweep Actuator, Assembly of
- 3109-100008 Bushing, Outer - Attach Fitting, Wing Sweep Actuator
- 3109-100009 Bushing, Inner - Attach Fitting, Wing Sweep Actuator

These detail drawings have been released to manufacturing for tool design and fabrication of one of the fittings during phase III. Refer to appendix A, figures 1 through 4.

DETAIL DESIGN

During the last part of phase I, preliminary design, a change was made in the concept of the wing sweep actuator attach fitting from a welded truss assembly to a machined die forging design. This was done to improve the low cost-saving, which resulted in comparing the cost of the welded assembly with the baseline cost, which was based on a titanium die forging. A considerable improvement was made. This change resulted in a production cost saving of 24.5 percent, as compared to 9.7 percent for the welded assembly.

A change has now been made in the design concept of the wing pivot shear fitting from a welded assembly to a machined die forging. This resulted from a new production cost comparison using recent quotes on the baseline titanium part rather than the actual costs of the B-1 DVT part. The high cost of an oversize forging on the DVT part produced a distorted baseline

value. Quotes were obtained from the same vendor on a steel die forging similar to the B-1 part. A new comparison showed a marked reduction in cost saving from 62.6 percent to around 30 percent. However, a comparison with the steel-welded design showed a much greater reduction. A new drawing was prepared of the steel die forging design and is used as the basis for a final cost saving on this candidate part.

On 1 February 1977, selection of the actuator attach fitting was made for fabrication and test. Final detail design has incorporated all requirements for tooling, fracture mechanics, and fabrication.

COST ANALYSIS

WING PIVOT SHEAR FITTING

The preliminary cost analysis on the wing pivot shear fitting was based on a design involving two-ring forgings welded together, end-to-end, to make one ring assembly from which three parts could be made by cutting it into three 120-degree segments after lathe turning and weld attaching several lugs for strut attachment and equipment mounting. The cost of this design was compared to a baseline titanium part cost resulting from actual part cost of the B-1 DVT part. This comparison yielded a predicted cost saving of 62.6 percent.

This value has been considered invalid due to the extremely oversized forging purchased for initial B-1 parts. During the detail design phase of the steel substitute part, a new cost estimate was made for a production baseline part based on actual quotes on an optimized titanium forging. This new cost, when compared to the steel substitute design cost, resulted in a reduction of cost saving far below the 30 percent level.

A quote was obtained on a substitute steel die forging from the same forging vendor supplying the titanium quote. A new cost estimate based on this design and compared to the new titanium part cost resulted in a predicted cost saving in the 30- to 40-percent range.

A new detail design of the wing pivot shear fitting now has been completed based on a completely machined die forging. A cost analysis based on actual detail drawings shows a potential cost saving of 42.14 percent. A sequence of cost analyses leading up to this final figure is shown in table 1 starting with the initial analysis and baseline developed in phase I. Changes affecting each subsequent analysis are:

- Analysis No. 2 - Revised baseline costs for a production size forging weighing 114 pounds.

Table 1

COST ANALYSIS AND COMPARATIVE SAVINGS WING PIVOT INBOARD SHEAR FITTING

1975 DOLLARS

	Baseline		Substitute	
	Ti Die Forging (DVT)		AF 1410 Steel Ring Forging	
Weight - B/F lb	500/48.6		Weldment 135.5/48.0	
	First Unit	300 U Cum Ave	First Unit	300 U Cum Ave
Analysis No. 1 (From Phase I)				
Material	$ 9,568	$ 7,784	$ 1,244	$ 1,012
Fabrication	5,974	743	15,129	2,082
Tooling	56,270	260	30,634	192
Total	$71,812	$ 8,787	$47,007	$ 3,286
Savings			34.5%	62.6%
Analysis No. 2 (11-26-76)	Ti Die Forging (Prod)		AF 1410 Steel Ring Forging	
Weight - B/F lb	114/48.6		Weldment 135.5/48.0	
Material		$ 2,387		$ 1,012
Fabrication		536		2,082
Tooling		211		192
Total		$ 3,134		$ 3,286
Savings		4.62%		

Table 1 (CONT)

COST ANALYSIS AND COMPARATIVE SAVINGS WING PIVOT INBOARD SHEAR FITTING

1975 DOLLARS

	Baseline		Substitute	
	Ti Die Forging (Prod)		AF 1410 Steel Die Forging	
Weight - B/F lb	114/48.6		104.65/48.0	
	First Unit	300 U Cum Ave	First Unit	300 U Cum Ave
Analysis No. 3 (12-16-76)				
Material		$ 1,641		$ 803
Fabrication		502		686
Tooling		284		224
Total		$ 2,427		$ 1,713
Savings				29.41%
Analysis No. 4 (1-7-77)			(Rough machining cost equivalent to Ti)	
Weight - B/F lb	114/48.6		120/48.0	
Material		$ 1,775		$ 875
Fabrication		532		646
Tooling		211		151
Total		$ 2,518		$ 1,672
Savings				33.59%

Table 1 (CONT)

COST ANALYSIS AND COMPARATIVE SAVINGS WING PIVOT INBOARD SHEAR FITTING

1977 DOLLARS

	Baseline		Substitute	
	Ti Die Forging (Prod)		AF 1410 Steel Die Forging	
Weight - B/F lbs	114/48.6		120/48.0	
	First Unit	300 U Cum Ave	First Unit	300 U Cum Ave
Analysis No. 5 (1-7-77)				
Material		$ 2,328		$ 1,722
Fabrication		685		832
Tooling		250		178
Total		$ 3,263		$ 2,732
Savings				16.27%
Analysis No. 6 (2-16-77) (Rev 3-31-77)			Forging raw material at $3.25/lb	
Material	$ 3,054	$ 2,485	$ 1,815	$ 1,476
Fabrication	5,447	1,025	6,636	1,244
Tooling	44,679	257	32,970	184
Total	$53,180	$ 3,767	$ 41,421	$ 2,904
Savings			22.1%	22.9%

- Analysis No. 3 - Changed substitute design to die forging.

- Analysis No. 4 - Revised steel rough machining cost to the same as titanium based on new premachining heat-treat data. Also increased steel forging weight.

- Analysis No. 5 - Revised forging costs on both baseline and substitute in accordance with vendors quotes and updated costs to 1977 dollars.

- Analysis No. 6 - Reduced baseline for final vendor quotes. Reduced substitute forging quotes based on lower cost of raw material per AFFDL/FBS data obtained from Universal-Cyclops Steel Co.

First unit costs were developed for only the final analysis (No. 6) since all intermediate analyses were exercises in developing the final cost.

WING SWEEP ACTUATOR FITTING

The baseline cost of the wing sweep actuator fitting was established in phase I and is shown in table 2 . The preliminary design cost comparison, based on machined die forgings on both the baseline part and the substitute part, showed a saving of 24.5 percent. This was based on an estimated buy/fly weight ratio of 4:1 and an estimated forging cost of $8.00 per pound.

A forging drawing was prepared in phase II and a calculated weight obtained. In addition, the cost of rough machining was reduced from 24 percent higher than titanium to equal to titanium. A revised analysis and cost comparison, analysis No. 2, as shown in table 2 , was made based on these changes and an actual vendor quote on the die forging. This comparison showed a savings of 28.34 percent for production. First unit costs were not obtained for this intermediate analysis.

An estimated cost of $1.50 to $1.80 per pound for forging ingot material was obtained from Universal-Cyclops through AFFDL/FBS. This value was provided to the forging vendor who then revised the forging quote accordingly. The final cost figures are shown as analysis No. 3 in table 2 and result in a cost saving of 31.0 percent. A comparison of first unit cost shows 2.27 percent saving of the baseline first unit cost.

Table 2

COST ANALYSIS AND COMPARATIVE SAVINGS WING SWEEP ACTUATOR ATTACH FITTING

1975 DOLLARS

	Baseline		Substitute	
	Ti Die Forging		AF 1410 Steel Die Forging	
Weight - B/F lb	537/172.2		591/147.85	
	First Unit	300 U Cum Ave	First Unit	300 U Cum Ave
Analysis No. 1 (From Phase I)				
Material	$ 11,713	$ 9,530	$ 6,359	$ 5,174
Fabrication	17,672	3,468	22,612	4,488
Tooling	124,018	611	124,018	612
Total	$153,403	$13,609	$152,989	$10,274
Savings			0.3%	24.5%
Analysis No. 2				
Material		$ 9,530		$ 5,174
Fabrication		3,468		3,966
Tooling		611		612
Total		$13,609		$ 9,752
Savings				28.34%

Table 2 (CONT)

COST ANALYSIS AND COMPARATIVE SAVINGS WING SWEEP ACTUATOR ATTACH FITTING

1977 DOLLARS

	Baseline		Substitute	
	Ti Die Forging		AF 1410 Steel Die Forging	
Weight - B/F lb	537/172.2		591/147.85	
	First Unit	300 U Cum Ave	First Unit	300 U Cum Ave
Analysis No. 3 Rev 3-31-77				
Material	$ 14,385	$11,703	$ 8,952	$ 7,284
Fabrication	23,319	4,577	26,367	5,234
Tooling	138,779	712	138,779	712
Total	$176,483	$16,992	$174,098	$13,230
Savings			1.47%	22.1%

WEIGHT ANALYSIS

A final weight calculation was made on the released detail designs of the two candidate parts. Baseline weights, as reported in NA-76-860, "Preliminary Design Report," page 19, are shown for comparison along with the new substitute design weights in table 3 . Weight breakdowns on each of the substitute detail designs are shown in table 4

Although weight saving was not a primary goal in this program, significant savings can be made by efficient design and through weight reduction of installation parts such as bolts, pins, and bushings due to shorter lengths required for thinner higher strength material. Reduced fixed weight in an aircraft results in considerable savings in operational costs.

Table 3

BASELINE WEIGHTS

Drawing No.	Title	Weight
L1100030-011	Fitting - Shear, Inboard Pivot Pin, Assy of	48.70
L1100030-005	Fitting	48.64
L1100063-003	Bushing	0.06
L3007214-001	Fitting - Wing Sweep Actuator, Inboard Attach, Assy of	176.30
L3007214-005	Fitting	172.20
L1200234-005	Bushing - Outer	1.96
L1200235-003	Bushing - Inner	2.14

Table 4

WEIGHT BREAKDOWN - AF1410 DESIGNS

3109-100010 Wing Pivot Inboard Shear Fitting

Machined body		43.08 lb
lugs		2.61 lb
brackets		.36 lb
	Total	46.05 lb

B-1 titanium baseline part	48.64 lb
Substitute weight saving	2.59 lb

Installation and assembly parts weight reduction due to reduced lug thicknesses and bolt grip lengths.

L1100048-003 bushing	0.003 lb
L1100063-003 bushing	.004 lb
L1100073-017 bushing	.475 lb
L1100073-009 bushing	.137 lb
5/8 dia bolts	.129 lb
7/8 dia bolts	.362 lb
	1.110 lb

Net weight savings = 1.11 + 2.59 = 3.70 lb
Net weight savings per airplane 2 x 3.70 = 7.40 lb

3109-100006 Wing Sweep Actuator Inboard Attach Fitting

-003 fitting	153.47 lb
3109-100008 bushing, outer	1.83 lb
3109-100009 bushing, inner	2.40 lb
	157.70 lb

B-1 titanium baseline assembly	176.30 lb
Fitting assembly weight difference	18.60 lb

Installation bolts and actuator attach pin weight reduction due to reduced grip lengths, bolt sizes (6 places) and lug thicknesses

L1200241-007 pin		-3.10 lb
bolts		-4.84 lb
	Total	-7.94 lb

Net weight savings 18.60 + 7.94 = 26.54 lb
Total weight savings per airplane 2 x 26.54 = 53.08 lb

STRESS ANALYSIS

WING PIVOT INBOARD SHEAR FITTING

The inboard shear fitting (figure 4) was analyzed using the structural analysis curves and material properties provided under "Structural Analysis Properties" (appendix B). The applied design loads are those obtained from the B-1 Stress Group and used for the titanium baseline part.

The shear fitting design is based on a machined die forging concept so that the design strength reductions for as-welded structure need not be imposed. The previous design had the diagonal shear strut attach lugs welded to the curved walls of the fitting. (Refer to phase I report, NA-76-860.)

A summary of critical margins of safety is presented in table 5 , in which margins less than +0.50 are listed. Typical analyses are provided in the following pages.

The critical conditions for the shear strut attachment lugs are the terrain-following and low-level penetration mission segment loads for lug tension and compression respectively (conditions 1-A and 1-B). The critical condition for the fitting sections (conditions 2-A or 2-B) is the case where the upper or lower outboard wing pivot lug fails and an induced thrust load, either up or down, occurs on the fitting.

The stress analysis of the shear fitting checks the shear strut attachment lugs for tension and compression strut loads. Stress checks of cross sections at various locations along the fitting wall were made for the effect of combined axial and bending stresses using assumed effective width sections. The effect of curved fitting wall cross sections were accounted for, in terms of locating bending eccentricities. No negative margins were identified for this analysis.

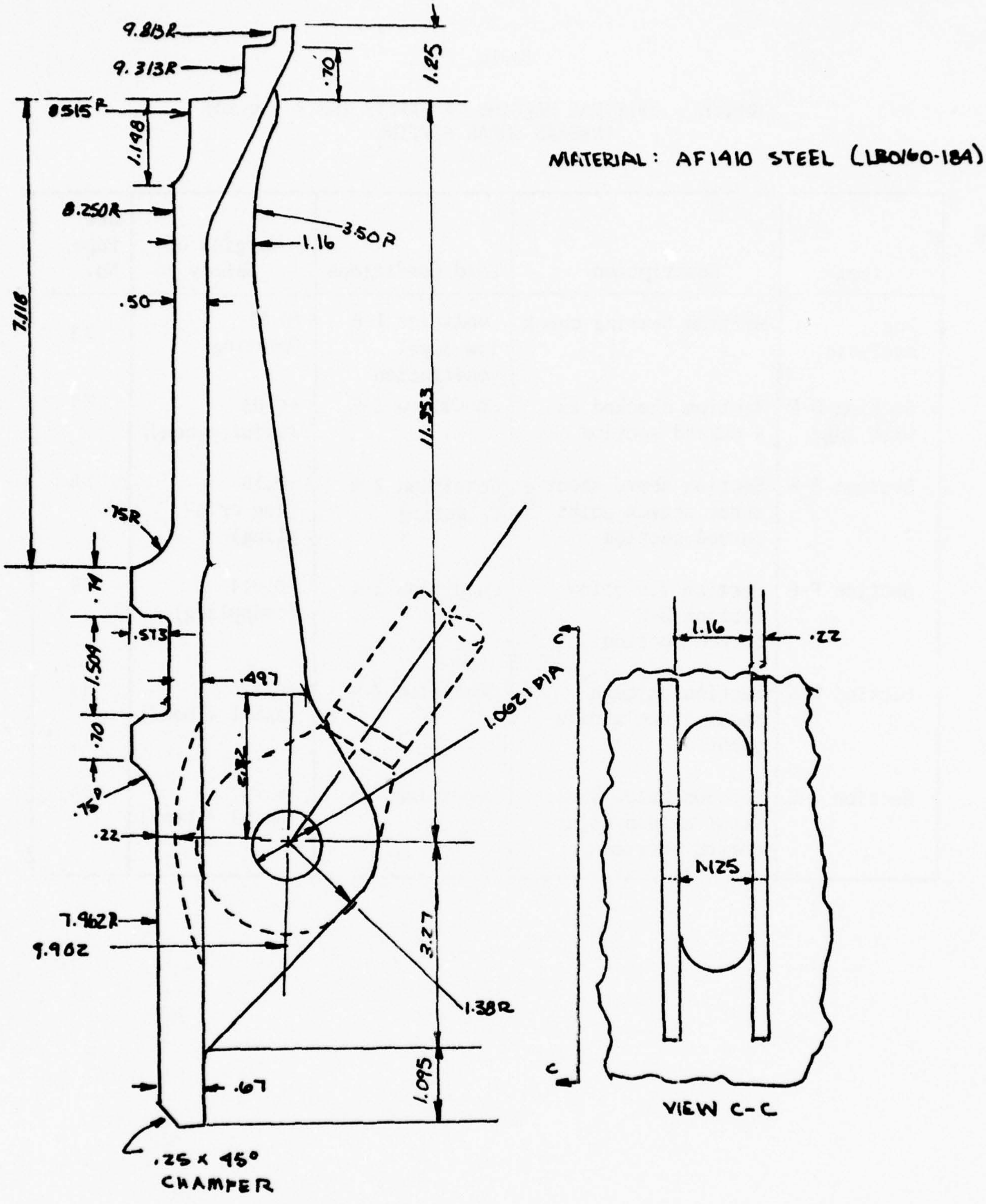


Figure 4 Wing Pivot Inboard Shear Fitting

Table 5

SUMMARY - CRITICAL MARGINS OF SAFETY (MS < + 0.50)
INBOARD SHEAR FITTING

Item	Description	Load Conditions	Margins of Safety	Ref Page No.
Lug analysis	Maximum bearing check	Condition 1-B low-level penetration	+0.31 (bearing)	23
Section D-D with lugs	Section checked as a curved section	Condition 2-B	+0.03 (axial + bend)	26
Section B-B	Section above shear strut attach point curved section	Condition 2-A P_L acting	+0.19 (lug crip-pling)	28
Section F-F	Section 2.9 below section B-B curved section	Condition 2-A	+0.014 (crippling)	29
Section K-K	Section through shear strut attach point	Condition 2-A	+0.27 (axial + bend)	33
Section C-C	Section below shear strut attach point curved section	Condition 2-A	+0.24 (axial + bend)	34

LOADS (ULTIMATE DESIGN LOADS)

The loads shown in table 6 are the same as used for the B-1 baseline titanium component. Three primary conditions govern the loads on the shear fitting:

1. Strut load - transfers shear to inboard rib at station 119.

2. Thrust load on fitting due to outer wing pivot lug half failure (upper or lower outboard).

3. Lug load components transferred by pin via the "notch and land" design of the shear fitting - pin system.

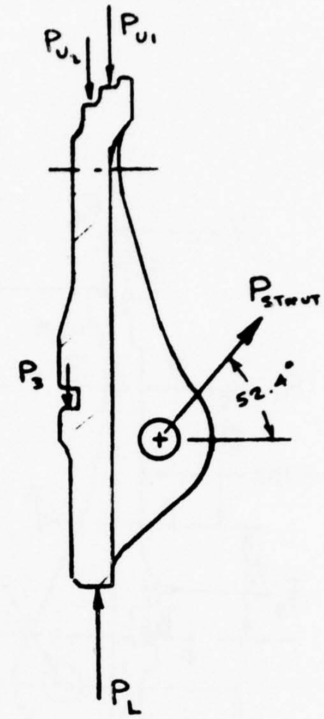


Table 6

TABLE OF ULTIMATE DESIGN LOADS

Cond.	P_{strut}	$P_L = P_3$	P_{u_1}	P_{u_2}	Descrip.
	(kips)	(kips)	(kips)	(kips)	
1-A	27.85				1 G - terrain follow.
1-B	- 107.94			4.77	Low level penetration
2-A		318.05			Fail. pivot lug half
2-B			64.1	3.18	Fail. pivot lug half
3				36.08	2 G - flap down

LOADS DEVELOPMENT (ULTIMATE LOADS)

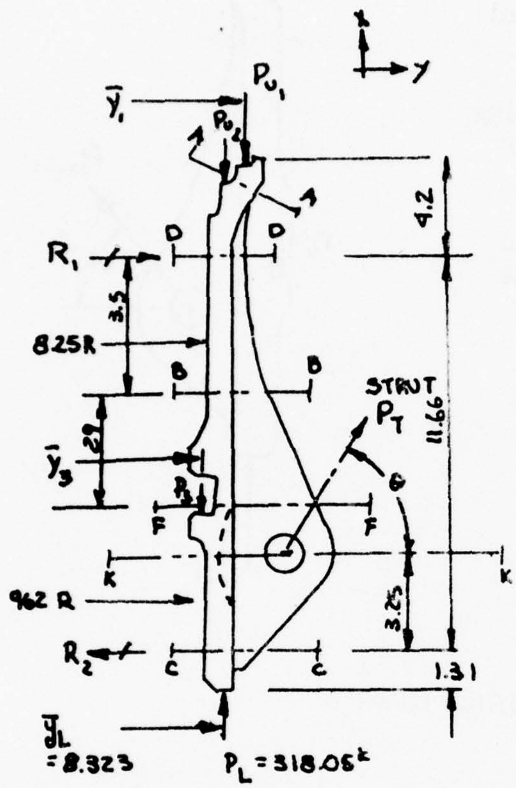


Figure 5
Analysis Section Locations

$P_{u_1} = 64.1$ K COND 2-B

$\bar{y}_1 = 9.471$ $(R_{u1} = 9.5)$

$P_{u_2} = 3.2$ K $(R_{u2} = 8.849)$

$M_{AA} = P_{u_1} x\ e = 64.1 \times 0.02$

$= 1.282$ IN-K (COND 2-B)

$R_1 = 18.08$ K $= -R_2$ (COND 2-A)

$M_{DD} = P_{u_1} \times e_1 + P_{u_2} \times e_2$

$= 58.35$ IN-K (COND 2-B)

$M_{BB} = R_1 \times 3.5 = 18.08 \times 3.5$

$= 63.28$ IN-K (COND 2-A)

$P_T = + 27.85$ K COND 1-A

$= - 107.94$ K COND 1-B

$\theta = 54.4°$

$P_3 = 318.05$ K COND 2-A

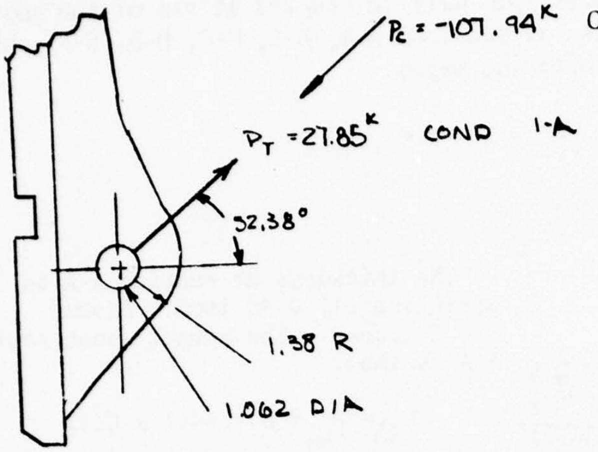
$\bar{y}_3 = 7.655$

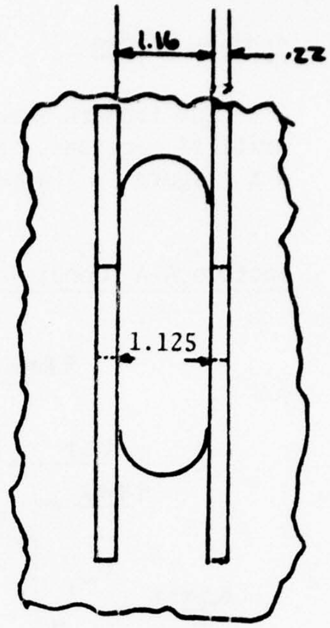
$M_{FF} = R_1 \times (3.5 + 2.9) = 115.712$ IN-K (COND 2-A)

$M_{FF} = 47.61$ IN-K (COND 1-A)

$M_{KK} = R_2 \times 3.25 + P_L \times e = 58.76$ IN-K (COND 2-A)

LUG ANALYSIS (CONDITION 1)





Assume a 60/40 load distribution of P_T and P_C to each lug.

$$e/D = 1.38/1.062 = 1.30$$

$$W/D = \frac{2 \times 1.38}{1.062} = 2.6$$

$$D/t = 1.062/.22 = 5.06$$

The bearing area A_{br} then equals $1.062 \times (0.22 - 0.03) = 0.191$ in.^{2}/lug and $A_t = (2 \times 1.38 - 1.062)(0.22) = 0.356$ in.^{2}/lug.

The analysis of the inboard shear fitting indicated that the most critical condition of the lug assembly is condition 1-B with $P_C = -107.94$ kips. The check for bearing of the lug appears as follows:

$$P_C = -107.94$$

The applied load is then 60% of -107.94 or -64.8 kips. The bearing stress $f_{br} = P_1/A_{br} = 64.8/0.191 = 339$ ksi.

$$F^{bru} = 446 \text{ ksi for } e/D\ 2.0$$ (Reference Appendix A)

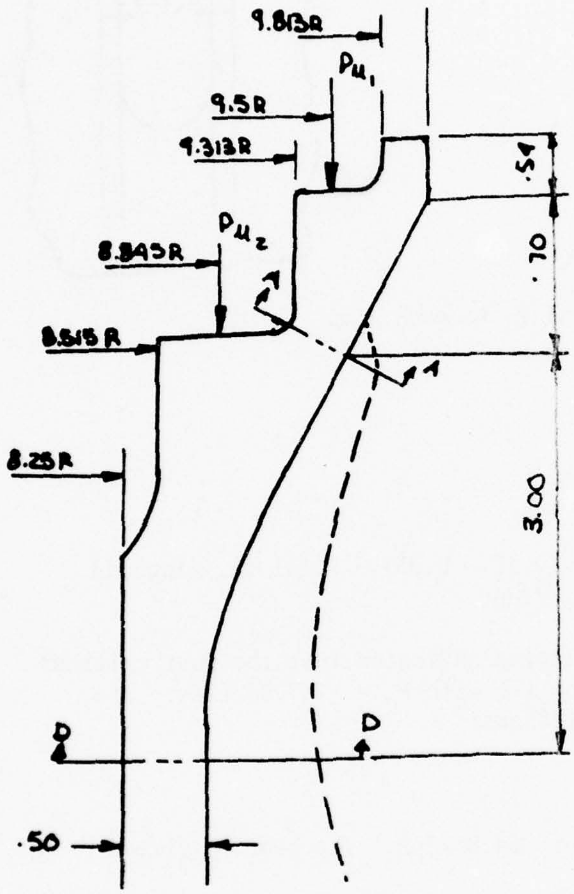
The bearing margin of safety is

$$MS = \frac{F^{bru}}{f_{br}} - 1 = \frac{446}{339} - 1 = \underline{+0.31}$$

SECTION CHECKS

The inboard shear fitting pivot pin will be checked at six of the most critical sections. Section checks at sections A-A, B-B, C-C, D-D, F-F, and K-K (figure 5) appear in the following pages.

Section A-A (Condition 2-B)



The thickness at section A-A is approximately 0.40 inch. Assume b = 2 inches. The moment about section A-A is then:

$$M_{AA} = P_{u_1} \times e = 64.1 \times 0.02$$

$$= 1.282 \text{ IN-K}$$

The compressive stress f_c is :

$$f_c = \frac{M \cdot c}{I} + \frac{P_{u_1}}{b \cdot t}$$

and $I = \frac{b\ t^3}{12}$, $c = t/2$

$$\text{so } f_c = \frac{6 \times 1.282}{2.\times (0.4)^2} + \frac{64.1}{0.4 \times 2}$$

$$= 104 \text{ ksi}$$

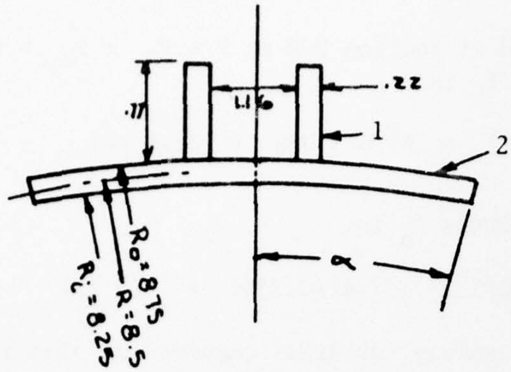
The compressive margin of safety is then:

$$MS = \frac{F^{cy}}{f_c} - 1 = \frac{226}{104} - 1 = \underline{+1.173}$$

Section D-D

Section D-D is treated as a curved section.

$$\bar{y}_1 = \frac{R \sin \alpha}{\alpha} = \frac{9.5 \times \sin 8.69°}{0.1516 \text{ radiars}} = 9.471 \text{ inches}$$



$$2\alpha = 5.4/8.5 = 0.6353$$

$$\alpha = 0.3176 = 18.2°$$

and the sine of $\alpha = 0.312$. $\bar{y} = \frac{R \sin\alpha}{\alpha} = 8.350$

$$y = R_o - \bar{y} = 0.40$$

$$e_1 = \bar{y}_1 - \bar{y}_D = 9.471 - 8.289 = 1.182 \text{ inches}$$

$$e_2 = \bar{y}_2 - \bar{y}_D = 8.822 - 8.289 = 0.533 \text{ inches}$$

Section	Area	Y	AY	AY^2	I_o
1	0.3388	0.385	0.1304	0.0502	0.0167
2	2.7	-0.40	-1.080	0.4320	0.0563
Σ	3.0388	$0.\overline{312}$	-0.9496	0.4822	0.0720

$$I = 0.4822 + 0.0720 - 0.312 \times 0.9496 = 0.2579 \text{ in.}^4$$

$$I/c = 0.2579/(0.77 + 0.312) = 0.2384$$

$$R_D = 8.75 - 0.312 = 8.438$$

$$\bar{y}_D = \frac{8.438 \times 0.312}{0.3176} = 8.289$$

The moment about section D-D is then:

$$M_{DD} = P_{u_1} (1.182) + P_{u_2} (0.533) = 77.47 \text{ IN-K}$$

The total load at section D-D is $P = P_{u_1} + P_{u_2} = 67.3$ kips. The compressive stress f_c is:

$$f_c = P/A = 67.3/3.039 = 22.1 \text{ ksi}$$

The bending stress f_b is:

$$f_b = Mc/I = 77.47/0.2384 = 325 \text{ ksi}$$

The margin of safety for axial compression plus bending is determined as follows:

$$R_c = \frac{f_c}{F_{cy}} = \frac{22}{226} = 0.097$$

$$R_b = \frac{f_b}{F_{cy} \times 1.5} = 0.959$$

The margin of safety is then:

$$MS = \frac{2}{R_b + \sqrt{R_b^2 + 4R_c^2}} - 1 = \underline{+0.03}$$

<u>Section B-B</u>

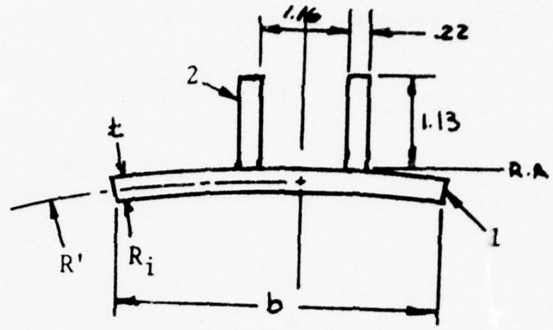
Section B-B is located at a typical section of the fitting above the strut attachment lug and below the build-up area at the top of the fitting (figure 5). This section will be checked for crippling due to the P_{u_1} and P_{u_2} loads.

For condition 2-A:

$$M_{BB} = R_1 \times 3.5 = 18.08 \times 3.5 = 63.3 \text{ IN-K}$$

For condition 2-B:

$$M_{BB} = P_{u_1} (e_1) + P_{u_2} (e_2) - R_1 \times 3.5$$



$$\bar{y}' = \frac{R' \sin\alpha}{\alpha} = \frac{8.5 \times 0.346}{0.353} = 8.331$$

$$2\alpha = \frac{b}{R} = \frac{6}{8.5} = 0.706, \qquad \alpha = 0.353 \text{ or } 20.22°$$

$$y = 8.74 - 8.331 = 0.409$$

Part	Area	Y	AY	AY^2	I_o
1	6 x 0.49	-0.409	-1.2025	0.4918	0.0588
2	2 x (0.22 x 1.13)	0.565	0.2778	0.1556	0.0528
Σ	3.436	-0.2691	-0.9247	0.6474	0.1116

$$c = 1.13 + 0.2691 = 1.399$$

$$I_x = \Sigma I_o + \Sigma Ay^2 - \bar{y}\Sigma Ay = 0.5102 \quad \text{and } I/C = 0.3647$$

$$\bar{y}_{BB} = 8.74 - 0.2691 = 8.4709$$

The bending stress $f_b = Mc/I = 63.3/0.3647 = 173.6$ ksi, COND 2-A

$$e_1 = 9.5 - 8.471 = 1.029 \text{ inches}$$

$$e_2 = 8.849 - 8.471 = 0.378 \text{ inches}$$

The load on section B-B is:

$$P_{BB} = P_{u_1} + P_{u_2} = 67.3 \text{ kips, COND 2-B}$$

The moment about section B-B is then equal to:

$$M_{BB} = P_{u_1} \times e_1 + P_{u_2} \times e_2 - R_1 \times 3.5$$

$$= 32.50 \text{ IN-K}$$

Assuming condition 2B, the bending stress now becomes 32.5/0.3647 = 89.1 ksi

and the axial compressive stress is:

$$f_c = P_{BB}/A = 67.3/3.436 = 19.59 \text{ ksi}$$

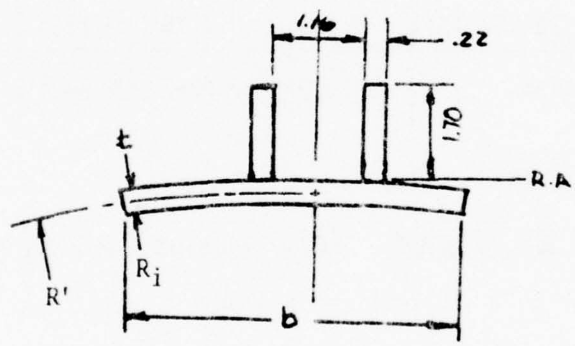
Assuming one edge is free, b/t = 1.13/1.22 = 5.136 and F_{cc} = 206 ksi. The crippling margin of safety for condition 2-A is critical:

$$MS = \frac{F_{cc}}{f_b} - 1 = \frac{206}{173.6} - 1 = \underline{+0.19}$$

<u>Section F-F</u>

Section F-F is located through the notched section of the fitting just above the strut attachment lug (figure 5). Through this notch the P_3 load is transferred to the fitting. This section will be checked for crippling and for bearing.

Lug dimension: t = 0.22, b = 1.70
Wall dimensions: t = 0.497, b = 6.00



$$R_i = 7.562 + 0.573 = 8.135 \text{ inches}$$

$$R' = 8.135 + 0.249 = 8.384 \text{ inches}$$

$$2\alpha = \frac{6}{8.384} = 0.7156$$

$$\alpha = 0.3578 \text{ or } 20.5°$$

$$\bar{y}' = \frac{R' \sin\alpha}{\alpha} = \frac{8.384 \times 0.35}{0.3578} = 8.201$$

$R_o - \overline{Y}' = 8.632 - 8.201 = -0.431$

Part	Dimensions	A	y	Ay	Ay^2	I_o
Lug	2 x 0.22 x 1.70	0.748	0.85	0.6358	0.5405	0.1801
Wall	6 x 0.497	2.982	-0.431	-1.2852	0.5539	0.0614
	Σ	3.730	$-0.\overline{1741}$	-0.6494	1.0943	0.2415

$$c = 1.70 + 0.174 = 1.874$$

$$I_x = \Sigma I_o + \Sigma Ay^2 - \overline{y}\Sigma Ay$$

$$\Sigma = 1.3358 - 0.1131 = 1.2227 \text{ in.}^4$$

$$I/c = 1.2227/1.874 = 0.652$$

The moment acting about section F-F is 115.72 K-IN (COND 2-A) The bending stress is then:

$$f_b = \frac{M_{FF}\, c}{I} = \frac{115.72}{0.652} = 177.5 \text{ ksi}$$

$$b/t = 1.70/0.22 = 7.33, \; F_{cc} = 180 \text{ ksi}$$

the margin of safety for crippling is:

$$MS = \frac{F_{cc}}{f_b} - 1 = \frac{180}{177.5} - 1 = \underline{+0.014}$$

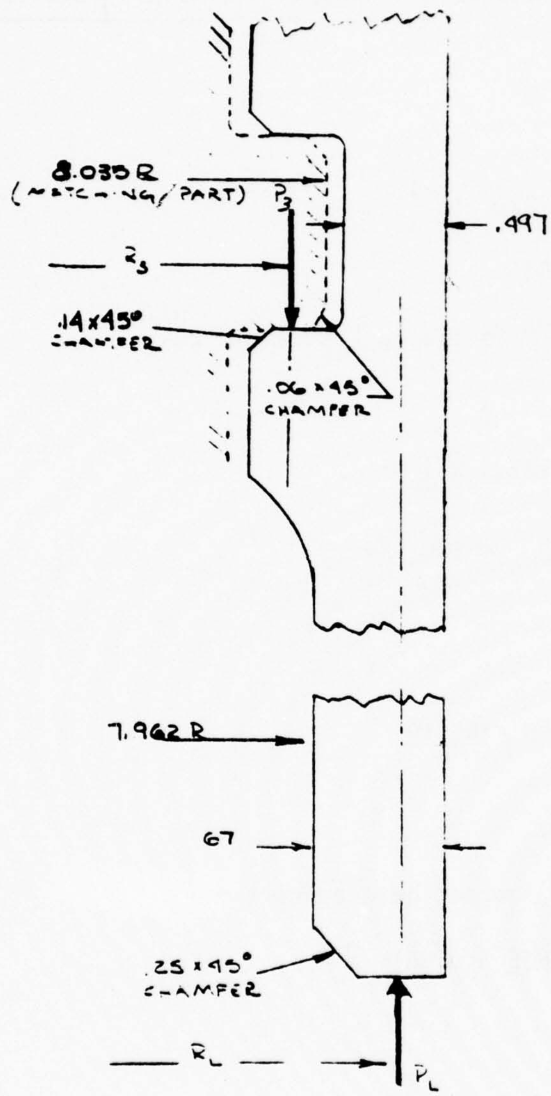
The fitting is now checked for bearing.

Assume R_3 acts at the midpoint of contact between parts:

$$R_3 = 0.5(7.562 + 0.14 + 8.035 - 0.06)$$

$$= 7.8385 \text{ inches}$$

The contact width = (8.035 -0.06) - (7.562 +0.14) = 0.273 inches



The bearing area is A_{br} and is equal to 6.5 x 0.273 = 1.774 in.^{2}

$P_L = P_3 = 318.05$ K and

$P_3' = 318.05 + P_T$ where

$P_T = \sin 52.383° \times 27.846$

$= 22.06$ K and $P_3' = 340.11$ K

The bearing stress f_{br} is found as:

$$f_{br} = \frac{P_3'}{A_{br}} = 191.7 \text{ ksi}$$

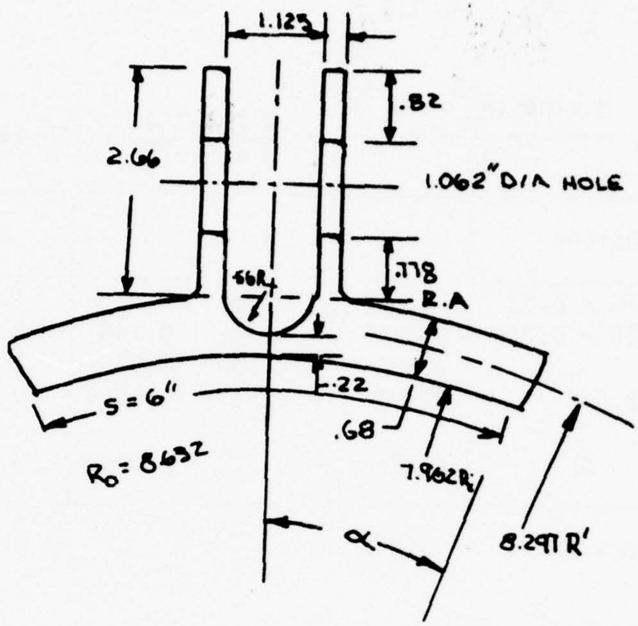
$F_{bru} = 330$ ksi (conservative)

The margin of safety is :

$$MS = \frac{330}{192} - 1 = \underline{+0.72}$$

Section K-K

Section K-K is located through the center hole of the strut attachment lug. This section will be checked for combined axial plus bending loads.



$$2\alpha = \frac{6}{8.797} = 0.72315$$

$$\alpha = 0.3616 = 20.72°$$

$$\sin\alpha = 0.354$$

$$\bar{y}' = \frac{R'\sin\alpha}{\alpha} = \frac{8.297}{0.3616} \times 0.354 = 8.123$$

$$y = 7.962 + 0.67 - 8.123 = 0.509 \text{ wall}$$

$$\text{semicircle} \quad y = 0.4244R = 0.4244 \times 0.56$$

$$= 0.237$$

$$\text{semicircle} \quad I_o = 0.1097R^4 = 0.0108$$

$$\text{Wall Area} = (R_o^2 - R_i^2)\,\alpha = 4.0202$$

$$\text{Wall } I_o = \frac{\alpha}{4}(R_o^4 - R_i^4)\left(1 + \frac{\sin\alpha\cos\alpha}{\alpha}\right) - A\bar{y}^2$$

$$\text{Wall } \bar{y} = \frac{2\sin\alpha\,(R_o^3 - R_i^3)}{3A} = \frac{2 \times 0.354}{3 \times 4.0202} \times 138.44 = 8.127$$

Section	Dimensions	Area	y	Ay	Ay^2	I_o
Lug	2 x 0.2375 x 0.82	0.3895	2.25	0.876	1.9718	0.0218
Lug	2 x 0.2375 x 0.778	0.3695	0.389	0.1437	0.0559	0.0186
Wall	6 x 0.67	4.02	-0.509	-2.0462	1.0415	0.1504
Wall	-1.571×0.56^2	-0.493	-0.237	+0.1168	-0.0277	-0.0108
	Σ	4.286	-0.212	-0.9097	3.0415	0.18

$$C = 2.66 + 0.218 = 2.878$$

$$I = \Sigma I_o + \Sigma A_y^2 - \bar{y}\Sigma A_y$$

$$= 0.18 + 3.0415 + 0.2122(-0.9097) = 3.028 \text{ in.}^4$$

$$\frac{I}{C} = \frac{3.028}{2.878} = 1.052$$

The load on section K-K is:

$P_{kk} = P_L = 318^k$ COND 2-A and the moment acting about section K-K is:

$$M_{kk} = R_2 \times 3.25 + P_L \times e = 87.698 \text{ IN-K}$$

The bending stress f_b is then:

$$f_b = \frac{M_{kk}\,c}{I} = 83.3 \text{ ksi}$$

The compressive axial stress is:

$$f_c = \frac{P_{KK}}{A} = \frac{318}{4.26} = 75 \text{ ksi}$$

$$b/t = 2.60/0.2375 = 11.2$$

F_{cc} then is 130 ksi (one edge free).

$$Rc = \frac{fc}{Fcy} = \frac{75}{226} = 0.332$$

$$R_b = \frac{fb}{F_{cc}} = \frac{83.3}{130} = 0.646 \quad \text{(Conservative)}$$

The margin of safety for axial compression and bending is:

$$MS = \frac{2}{R_b + \sqrt{R_b^2 + 4 R_c^2}} - 1$$

$$= +0.27$$

Section C-C

Section C-C is located 1.31 inches above the foot of the fitting. This section will be checked for combined axial and bending loads.

$R_L = 7.962$ in. $R_o = 8.632$ in $R = 8.297$ in

$t = 0.67$ in.

$P_c = P_L = 318$ K COND 2-A

The moment about section CC is

$M_{cc} = P_L (\bar{y}_L - \bar{y})$ with $\bar{y}_L = 8.323$

To determine $\bar{y}$:

Let $w = 4.56$

$2\alpha = W/R = 4.56/8.297 = 0.5496$

and $\alpha = 0.275$ or $15.74°$ the sine of $\alpha = 0.2715$

$\bar{y}$ can be calculated as:

$$\bar{y} = \frac{R \sin\alpha}{\alpha} = \frac{8.297 \times 0.2715}{0.275}$$

$$= 8.191$$

M_{cc} is then 318(8.323 - 8.191) = 42 IN-K

The area at section C-C is $4.56 \times 0.67 = 3.05$ in.^{2}

$$I/c = \frac{bt^2}{6} = \frac{4.56(0.67)^2}{6} + 0.341$$

The axial stress is found to be: $f_c = \frac{P_c}{A} = 104$ ksi

and the bending stress is: $f_b = \frac{Mc}{I} = 123$ ksi

R_c is then $\frac{fc}{Fcy} = \frac{104}{226} = 0.460$ and $R_b = \frac{fb}{Fcy} = \frac{123}{226} = 0.544$ (Conservative)

The margin of safety is: $$MS = \frac{2}{R_b + \sqrt{R_b^2 + 4 R_c^2}} - 1 = \underline{+0.240}$$

WING SWEEP INBOARD ACTUATOR FITTING

The stiffened web design (machined forging) was chosen as the final candidate for validation of the AF1410 steel.

The analysis used the structural analysis curves and AF 1410 steel material properties under Appendix B, Structural Analysis Properties. The applied design loads were the same as those used by the B-1 Stress Group for the titanium baseline component. Conventional stress analysis techniques were used per references 1 and 2.

A summary of margins of safety are presented in table 8 in which margins less than +0.50 are listed. Typical analyses are provided in the following pages.

The critical loads and conditions (figure 6) have been identified as an actuator tension load (condition 1) and a compressive load (condition 2) of approximately 70 percent of the tension load magnitude. The support fitting serves to transfer the outer wing sweep loads into the wing carry-through structure via the YF932 bulkhead and ribs at XF121 and XF84.

The stress analysis of the machined forging-stiffened web design checked the fitting attachments to the substructure for shear and tension, the webs for shear buckling, and the caps for axial tension and/or compression. The actuator attachment lug region was checked for the maximum actuator load case of 922K tension. No negative margins were identified in the analysis.

Table 7

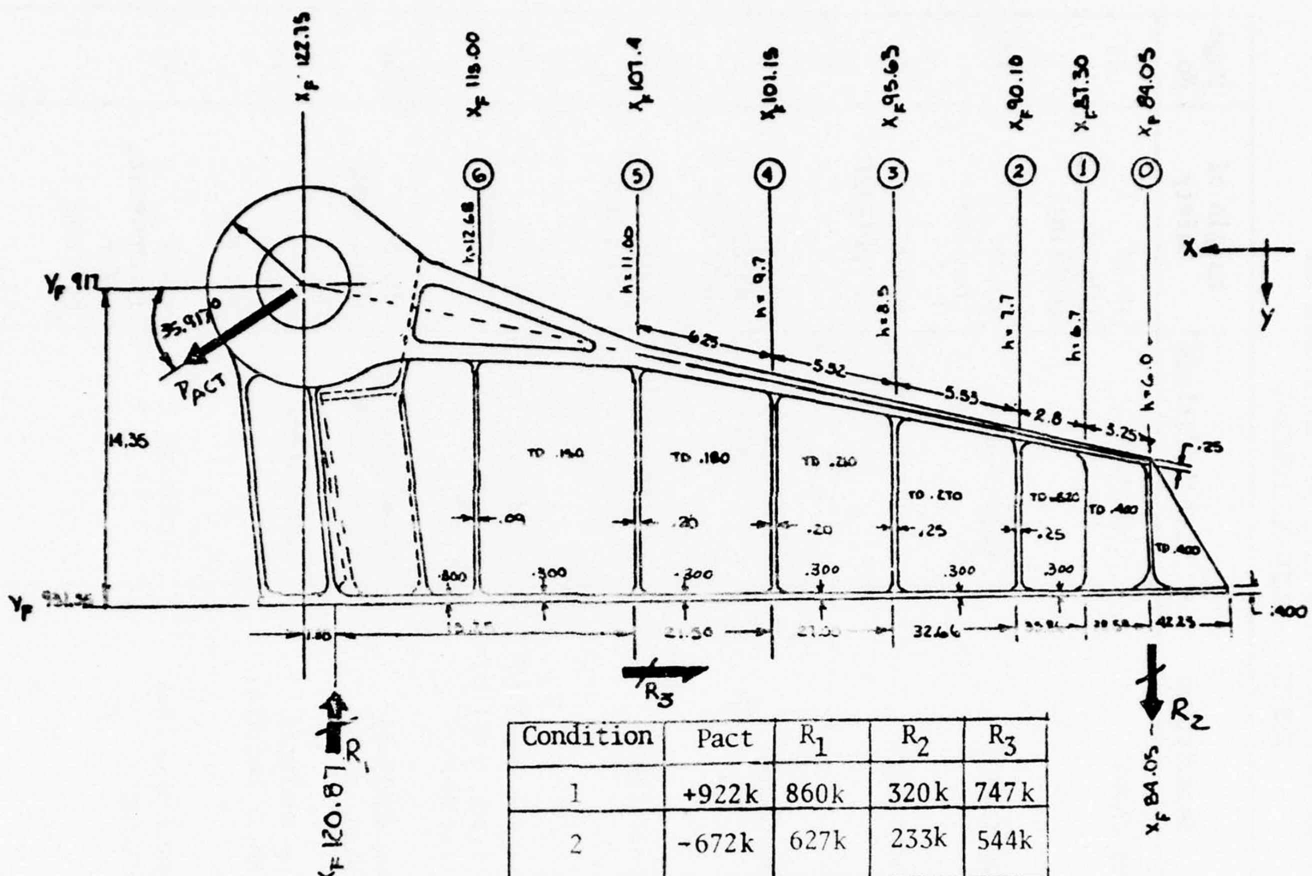
SUMMARY - CRITICAL MARGINS OF SAFETY (MS < 0.50)
INBOARD SWEEP ACTUATOR FITTING - STIFFENED WEB
DESIGN - MACHINED FORGING

Item	Description	Load Conditions	Margin of Safety	Page No.
Fastener check	Fasteners at X_F 84.05	P_{ACT} = 922K Condition 1-B	+0.46 (attach shear & tension)	43
Fastener check	Fasteners at X_F 121	P_{ACT} = -672 K Condition 2-A	+0.08 (attach shear & tension)	44
X_F 84.05	Web check	Condition 1	+0.10 (shear)	
X_F 87.3	Web check	Condition 1	+0.05 (shear & buckling)	45
X_F 90.1	Upper flange	Condition 1	+0.18 (tension)	45
X_F 95.63	Web check	Condition 1	+0.05 (shear buckling)	45
X_F 95.63	Upper cap	Condition 1	+0.20 (tension)	45
X_F 95.63	Lower cap	Condition 1-B	+0.30 (crippling)	45
X_F 101.15	Web check	Condition 1	+0.07 (shear-buckling)	47
X_F 101.15	Upper cap	Condition 1	+0.21 (tension)	48
X_F 101.15	Lower cap	Condition 1-B	+0.17 (crippling)	48

Table 7 (CONT)

SUMMARY - CRITICAL MARGINS OF SAFETY (MS < 0.50)
INBOARD SWEEP ACTUATOR FITTING - STIFFENED WEB
DESIGN - MACHINED FORGING

Item	Description	Load Conditions	Margin of Safety	Page No.
X_F 107.4	Web check	Condition 1	+0.08 (shear-buckling)	45
X_F 107.4	Upper cap	Condition 1	+0.24 (tension)	45
X_F 107.4	Lower cap	Condition 1-A	+0.01 (crippling)	45
Section X_F 115.0	Web check	Condition 1	+0.03 (shear buckling)	45
X_F 115.0	Lower cap	Condition 1-A	+0.10 (crippling)	45
Y_F 923.35	Section check of forging under pin attachment	Condition 1	+0.42 (crippling)	49
Lug X_F 122.75	Lug analysis (shear-out)	Condition 1 P_{ACT} = 922K	+0.16 (shear-out)	50
Lug X_F 122.75	Lug analysis (shear bearing)	Condition 1	+0.40 (shear bearing)	51
Lug X_F 122.75	Transverse shear-bearing	Condition 1	+0.45 (transverse, shear bearing)	52



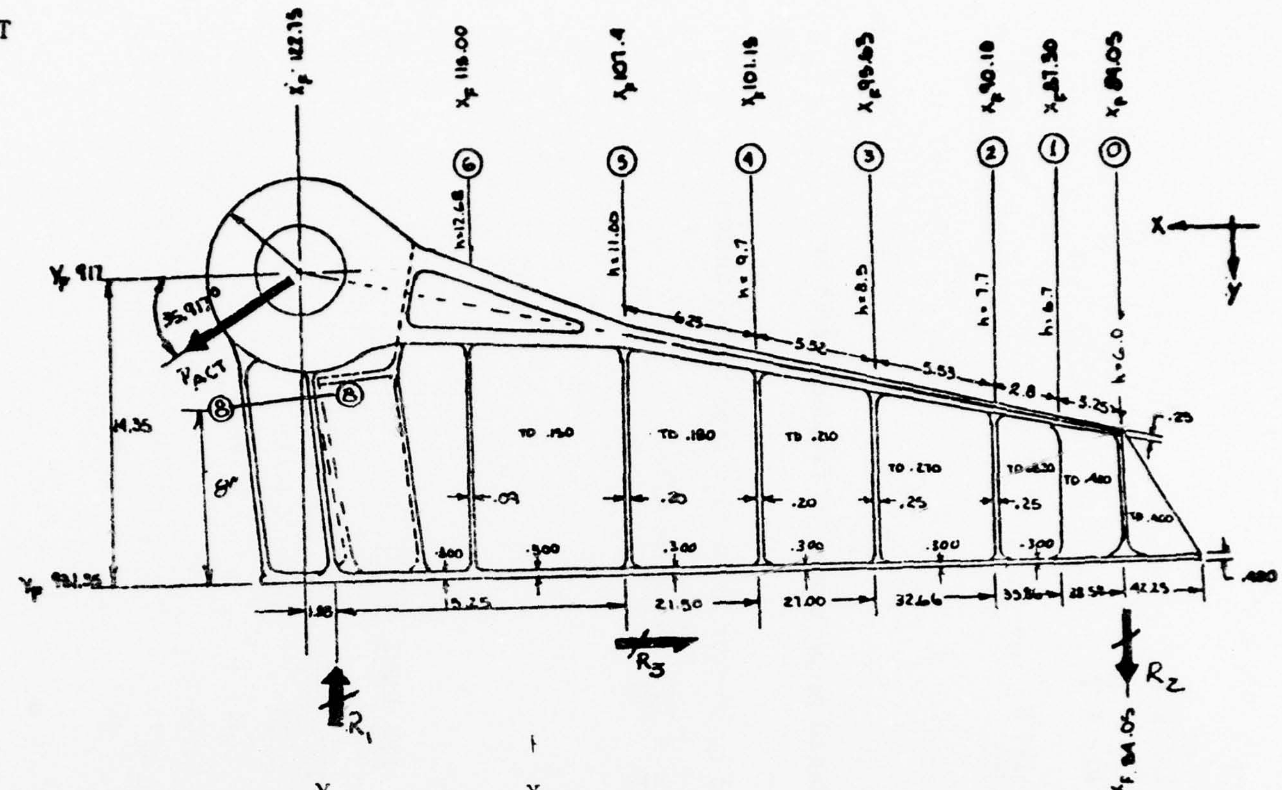
Condition	Pact	R_1	R_2	R_3
1	+922k	860k	320k	747k
2	-672k	627k	233k	544k

ULTIMATE LOADS

Material: AF1410 Steel (LBO 160-184)
Ref: Dwg 3109-100006

Figure 6 Loads and Dimensional Thickness Summary Wing Sweep Actuator Fitting

LOADS DEVELOPMENT



REACTIONS

<u>Condition 1:</u> $P_{ACT} = 922$ kips, $P^{Y}_{ACT} = 541$ K, $P^{X}_{ACT} = 747$ K

$$R_2 = 922 \times \left\{ \frac{\text{SIN } 35.917° \times 1.9}{36.82} + \frac{\text{COS } 35.917° \times 14.35}{36.82} \right\}$$

$= 320$ K

$$R_1 = 541 \times \frac{38.7}{36.82} + 747 \times \frac{14.35}{36.82} = 860 \text{ K}$$

$$R_3 = 922 \times \text{COS } 35.917° = 746.9 \sim 747 \text{ K}$$

Condition 2: $P_{ACT} = -672$ K

$$R_2 = \frac{672}{922} \times 320 = 233 \text{ K}$$

$$R_1 = \frac{672}{922} \times 860 = 627 \text{ K}$$

$$R_3 = \frac{672}{922} \times 747 = 544 \text{ K}$$

Reaction Load Distribution

Case A Let R_3 be distributed proportional to fastener areas or allowables.

Case B Let R_3 be reacted by uniform shear flow over L = 41 inches

$$q = \frac{R}{L} = \frac{747}{41} = 18.22 \text{ K/IN}$$

Cap Loads, Web Shears

See figure 7

Cap Areas (in.^{2})

Section	Upper Cap	Lower Cap
2	1.39	1.81
3	2.34	1.70
4	3.00	1.70
5	3.75	1.70
6	7.49	1.70

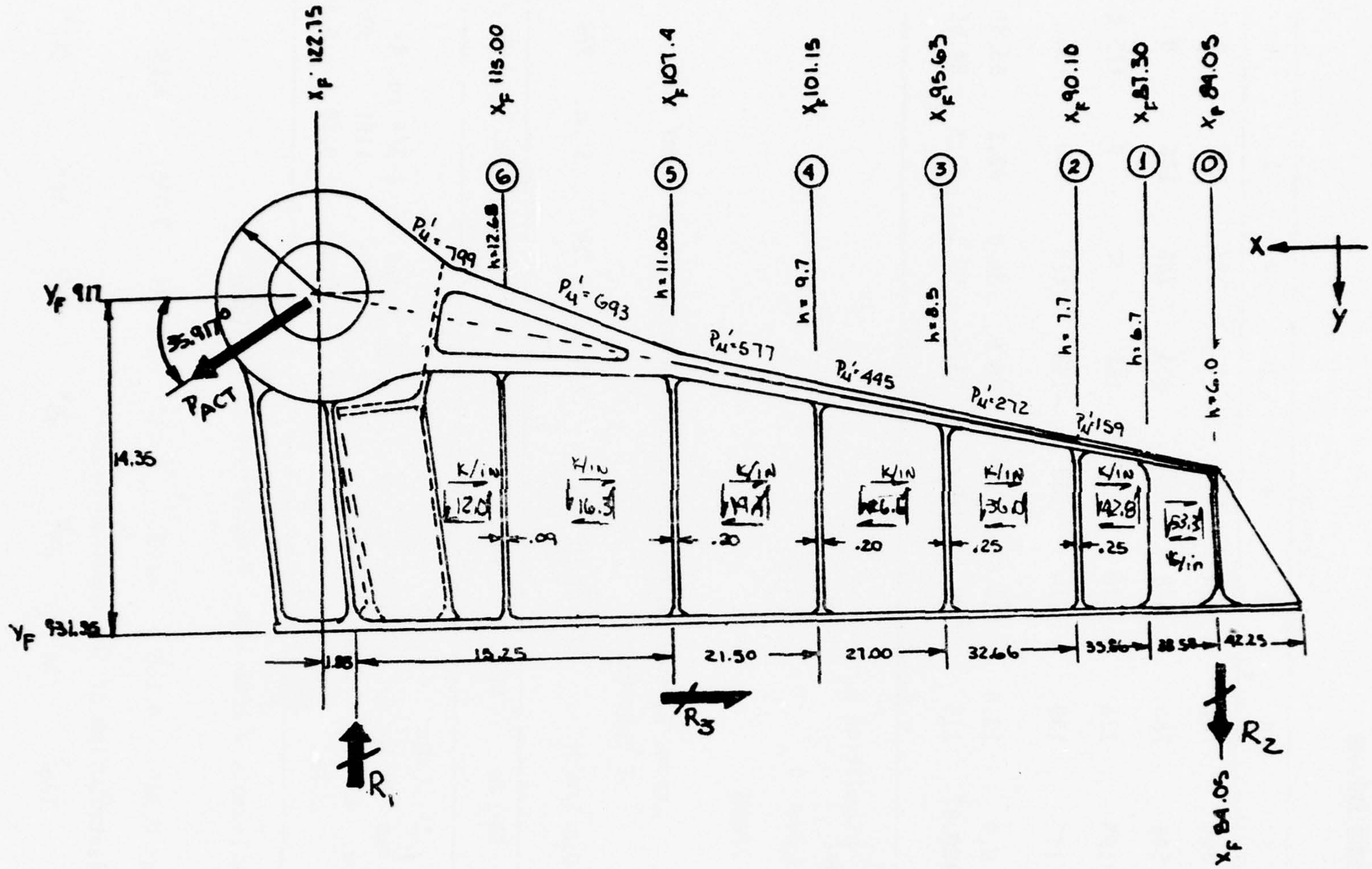


Figure 7 Shear Flows and Cap Loads

CAP LOADS, WEB SHEARS

Load	Section 7	6	5	4	3	2	1	0
P_u' (K)	864	799	693	569	445	272	159	0
P_U (K)	845	780	678	557	435	265	155	0
P_L* (K)	-195	-223	-245	-207	-168	- 77	- 8	+73.5
P_L**(K)	-135	-180	-216	-209	-188	-118	- 59	+36
q (K/IN)	9.9	12.0	16.3	19.4	26.6	36.0	42.8	53.3†
X_F	120.87	115	107.4	101.2	95.6	90.1	87.3	84.05

* Case A } Condition 1
** Case B }

† See figure 7

ATTACHMENT LOADS

Case A   Assume R_3 reacted proportional to allowables or shear area of fasteners.

P^{su}: Dia 3/4 in.   Allowable = 55K;   7/8 in. = 75K;   1 in. = 98K

X_F	120.87	111.3	104.3	98.5	93	88.7	84.05
Fasteners	2 - 1 in. +4-7/8 in.	6-3/4 in.	4-3/4 in.	4-3/4 in.	4-3/4 in.	2-3/4 in.	4-1 in.
Shear Allow.	496K	330K	220K	220K	220K	110K	392K
t (in.)	0.40	0.30	0.30	0.30	0.30	0.30	0.40

Σ Shear Allowable = 1988 Kips, Proportion $= \dfrac{\text{Shear Allow}}{\Sigma \text{ Allow}}$

Proportion:	0.249	0.166	0.111	0.111	0.111	0.055	0.197

The distribution of the reaction R_3 is:

$\Delta R_3' =$	186^k	124^k	83^k	83^k	83^k	41^k	147^k

Case B - **Uniform shear** distribution of R_3 over the length between R_1 and R_2 is 41 inches.

$$q = \frac{747}{41} = 18.22 \text{ K/IN}$$

The shear distribution is then:

X_F	120.87	111.3	104.3	98.5	93	88.7	84.05
ΔR_3	149 K	135 K	114 K	101 K	102 K	51 K	95 K

Attachment check at X_F 84.05 (220 HT bolts) There are four 1 inch fasteners, $P^{su} = 98^k$, $P^{tu} = 141^k$.

R_2 is 320 kips tension, R_3', case A, equals 147^k.

$$R_T = \frac{320}{141 \times 4} = 0.568$$

$$R_S = \frac{147}{98 \times 4} = 0.376$$

Assuming a circular interaction equation, the margin of safety (MS) for attachment shear and tension is:

$$MS = \frac{1}{\sqrt{R_T^{\,2} + R_S^{\,2}}} - 1 = \frac{1}{0.682} - 1 = \underline{+0.46}$$

Attachment Check at X_F 121 (220 HT Bolts)

(2) Two 1-inch dia bolts + (4) Four 7/8-inch dia bolts

$P^{su} = 98^k$/bolt $\qquad P^{su} = 75^k$/bolt

$P^{tu} = 141^k$/bolt $\qquad P^{tu} = 108^k$/bolt

$$\text{Allow } P_{tu} = 2 \times 141 + 4 \times 108 = 714K$$

$$\text{Allow } P_{su} = 2 \times 98 + \quad \times 75 = 496K$$

$$\left.\begin{aligned} &\text{Applied } P_T = \frac{672}{922} \times 860^k = 626K \text{ (Ten)} \\ &\text{Applied } P_S = \frac{672}{922} \times 186^k = 136K \text{ (Shr)} \end{aligned}\right\} \text{Cond 2A}$$

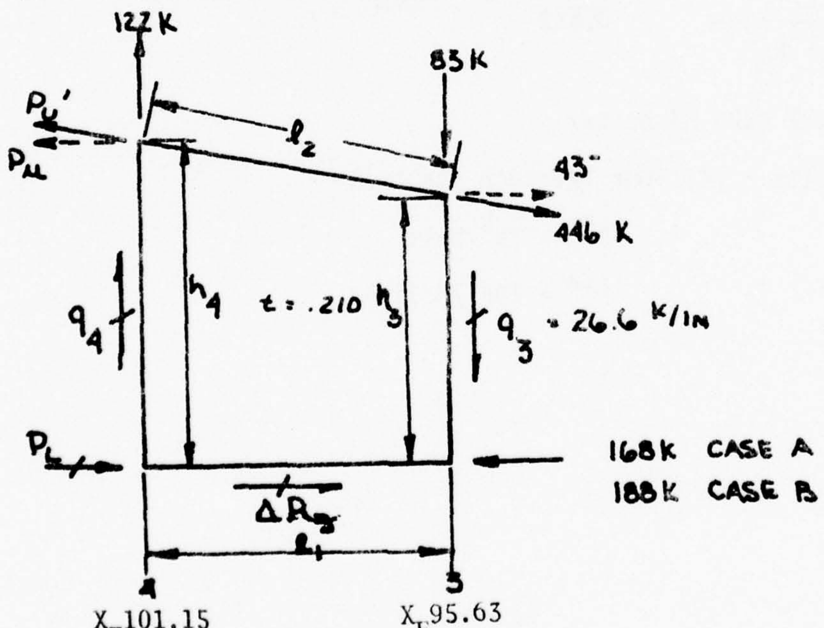
$$R_S = {}^{P_S}/_{P_{su}} = 136/456 = 0.298$$

$$R_T = {}^{P_T}/_{P_{tu}} = 626/714 = 0.877$$

$$MS = \frac{1}{\sqrt{R_S^2 + R_T^2}} - 1 = \frac{1}{\sqrt{0.858}} - 1 = \underset{\text{Shr + Ten}}{\text{(Attach.)}} \quad \underset{\text{Cond 2A}}{\underline{+0.08}}$$

SECTION CHECK

There were six main section checks of the webs on the actuator fitting. Figure 6 shows the position of each section. Each of these checks consisted of margin of safety calculations for web shear buckling, upper cap tension and compression, lower cap compression, and interrivet buckling in the lower cap. Shown here is a typical section check including each of the aforementioned components. Table 8 is a summary of the margin of safety calculations for the six sections checked.



$$V_{web} = 26.6 \times 8.5 = 226K$$

Table 8

SUMMARY OF MARGIN-OF-SAFETY CALCULATIONS
CONDITION I

Section X_F	Web Check Shear Buckling	Upper Cap Flange Tension	Lower Cap Crippling	Inter-Rivet Buckling
87.3 1-1	$+0.05^A$	$+0.18^A$	High^B	High^B
90.10 2-2	$+0.15^A$	$+0.18^A$	$+1.04^B$	High^B
95.63 3-3	$+0.05^A$	$+0.20^A$	$+0.30^B$	$+0.95^B$
101.15 4-4	$+0.07^A$	$+0.21^A$	$+0.17^B$	$+0.76^B$
107.40 5-5	$+0.08^A$	$+0.24^A$	$+0.01^A$	$+0.50^B$
115.0 6-6	$+0.03^A$	$+1.16^A$	$+0.10^B$	$+0.65^A$

NOTE: Superscript indicates attachment loading assumption.

A - R_3 reacted proportional to allowables or shear area of fasteners.

B - Uniform shear distribution.

For section V_F 101.15 (4-4):

$$P_{u_4} = \frac{[\ell_3 \times (V_3 + V_{web})] + P_{u_3} \times h_3}{h_4}$$

and $$P_{u_4} = \frac{5.52 \times (83 + 226) + 435 \times 8.5}{9.7}$$

$$= \frac{5403}{9.7} = 557 \text{ kips}$$

Then, $$P'_{u_4} = \frac{\ell_2}{\ell_1} \times P_{u_4} = \frac{5.64}{5.52} \times 557 = 569 \text{ kips}$$

$$P^V_{u_4} = \frac{h_4 - h_3}{\ell_1} \times P_{u_4} = \frac{1.2}{5.52} \times 557 = 121.08 \text{ kips}$$

$$V = 226 + 83 - 121 = 188K$$

from which q_4 can be determined as,

$$q_4 = \frac{V}{\bar{h}_2} = \frac{188}{9.7} = 19.38 \text{ K/IN}$$

The lower cap shearing force P_{L_4} can be determined now. Both attachment loading assumptions will be checked.

Case A R_3 reacted proportional to allowables or shear area of fasteners

$$P_{L_4} = 435 - 557 - 168 + 83 = -207K$$

Case B Uniform shear distribution.

$$P_{L_4} = -557 + 18.22(X_F\ 101.15 - X_F\ 82.05) = -209K$$

The web is now checked for shear buckling.

$$t = .210$$

$$f_s = \frac{q\ av}{.210} = \frac{(19.4 + 26.6)}{2 \times .210} = 109.5 \text{ ksi}$$

$$f_{s_{max}} = \frac{q_3}{.210} = \frac{26.6}{.210} = 126.6 \text{ ksi}$$

The ratio b/t is now determined such that b is the web length and t is the thickness.

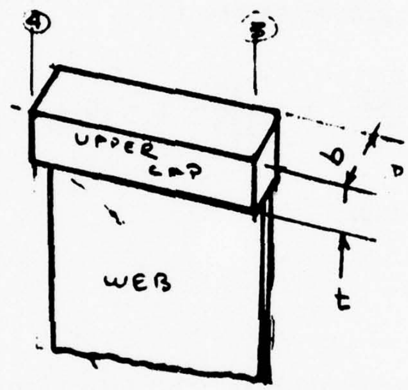
$$\frac{b}{t} = 26.3 ,$$

and $F_{s,cr}$ is found from Appendix B as 135 ksi.

The webshear buckling margin of safety is

$$M\ S\ (\text{Shear Buckling}) = \frac{F_{s,cr}}{f_{s_{max}}} - 1 = \frac{135}{126.6} - 1 = \underline{+0.066}$$

The upper cap is now checked;



The area of the cap $A_c = 0.80 \times 3.35 = 3.0\ \text{in.}^2$

$$f_t = \frac{P'_{u_4}}{A_c} = \frac{569}{3.0} = 189.7\ \text{ksi} \qquad \text{Cond 1}$$

$$F^{tu} = 230\ \text{ksi}$$

$$f_c = \frac{-672}{922} \times f_t = -138\ \text{ksi} \qquad \text{Cond 2}$$

$$\frac{b}{t} = \frac{3.75}{2 \times 0.8} = 2.34$$

$$Fcc = Fcy = 226\ \text{ksi}$$

The margin of safety for cap tension is:

$$M\ S\ (\text{Cap Tension}) = \frac{F^{tu}}{f_t} - 1 = \frac{230}{189.7} - 1 = +\ \underline{0.212} \quad \text{Cond 1}$$

The lower cap area $A'_c = 5.66 \times 0.30 = 1.70\ \text{in.}^2$

$$fc = \frac{PL}{A'_c} = \frac{209}{1.70} = 123\ \text{ksi} \quad (\text{Case B})$$

$$\frac{b}{t} = \frac{5.66}{2 \times 0.30} = 9.43$$

$$F_{cc} = 145\ \text{ksi}$$

The lower cap crippling margin of safety is:

$$MS\ (\text{crippling}) = \frac{F_{cc}}{f_c} - 1 = \frac{145}{123} - 1 = \underline{+0.17} \qquad \text{Cond 1-B}$$

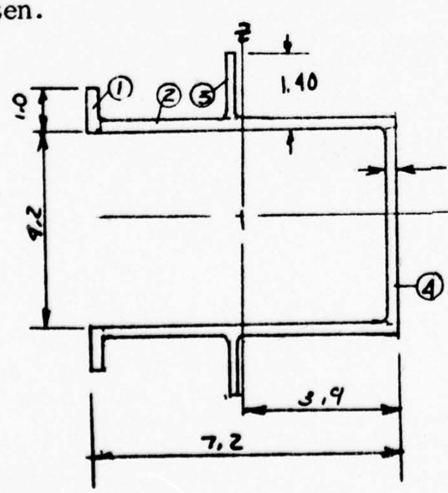
Check for interrivet buckling.

$$\frac{S}{t} = \frac{2.9}{0.30} = 9.66$$

$F_{cr}^{IR} = 216$ ksi (Appendix B) and the interrivet margin of safety is:

$$MS\ (\text{interrivet buckling}) = \frac{216}{123} - 1 = \underline{+0.76}$$

In addition to the section checks of the major webs, a check of a section of the fitting under the lug was checked for crippling. Y_F 923.35 was chosen.



Y_F 923.35 SECTION ⑧-⑧

Area=6.66 in.^{2}

The axial load on the cross-section is determined by

$$P_{axial} = R_1 \times \frac{\sqrt{1.88^2 + 14.35^2}}{14.35} = \frac{14.473}{14.35} \times 860 = 867 \text{ kips}$$

and the shear load is: $P_s = \frac{1.88}{14.35} \times 860 = 113$ kips

The axial stress is $f_c = P/A = \frac{867}{6.66} = 130$ ksi

$$\frac{b}{t} = \frac{1.40}{0.30} = 4.7 \text{ (one edge free)} \quad F_{cc} = 226 \text{ ksi}$$

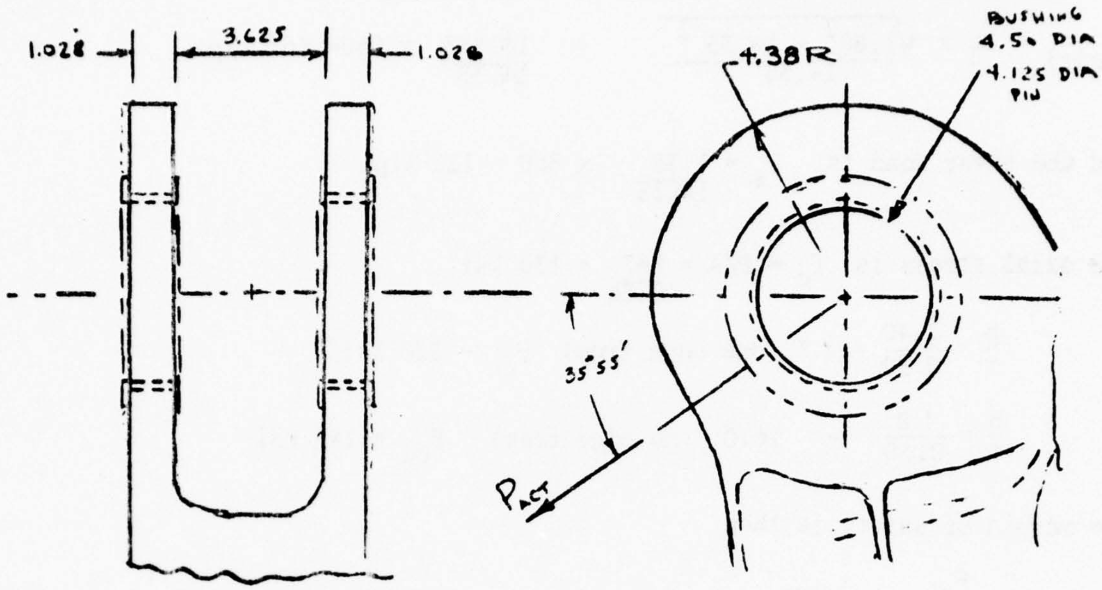
$$\frac{b}{t} = \frac{4.8}{0.30} = 16.0 \text{ (no edge free)} \quad F_{cc} = 185 \text{ ksi}$$

The margin of safety is then

$$MS = \frac{F_{cc}}{F_c} - 1 = \frac{185}{130} - 1 = + \underline{0.42 \text{ Crippling}}$$

LUG CHECK

Condition 1 with P_{act} = 922 kips produces the greatest load on the actuator lug. The lug will be checked for shearout, shear-bearing, and net tension.



First, the lug will be checked for shear-out. From Appendix B table A-I, F_{su} = 147 ksi, we can assume a 60-40 load distribution of the actuator load, P_{act}. The shear out load then becomes:

$$P^{so} = F^{su} \left(R - \frac{D}{2}\right) \times 2\,t$$

$$= 147 \left(4.38 - \frac{4.50}{2}\right) \times 2 \times 1.028$$

$$= 644 \text{ kips/lug allowable}$$

and the applied P_{lug} = 0.60 x 922 = 533 kips. The margin of safety is:

$$MS = \frac{P^{so}}{P_{lug}} - 1 = \frac{644}{553} - 1 = \underline{+0.16 \text{ shear-out}}$$

The lug is also checked for shear bearing -

$$\frac{D}{t} = \frac{4.5}{1.026} = 4.39 \quad \text{and} \quad \frac{e}{D} = \frac{4.38}{4.5} = 0.973$$

K_{br} from reference 1 is 0.73. From this the ultimate shear bearing per lug is:

$$F^{bru} = K_{br}\, F_{tu}\, A_{br} = 0.73 \times 230 \times 4.5 \times 1.026$$

$$= 775 \text{ K/}_{lug}$$

The load on the lug is $P_{lug} = 0.60 \times P = 553$ K. From this we can determine the shear-bearing margin of safety as:

$$MS = \frac{P_{bru}}{P_{lug}} - 1 = \frac{775}{553} - 1 = +\underline{0.40} \text{ (Shear Bearing)}$$

Net Tension

We can assume $W/D = \dfrac{2 \times 4.38}{4.5} = 1.947$

K_t from reference 1 is found to be 0.97. Therefore, the ultimate tension load is:

$$P_{tu} = k_t F_{tu} A_t' = 0.97 \times 230 \times (4.38 - 2.25) 2 \times 1.026$$

$$= 97.5 \text{ K/lug}$$

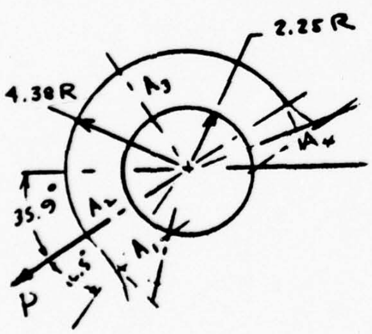
and the load distribution on the lug is

$$P_{lug} = 0.60 \times P = 553 \text{ K}$$

and from this the margin of safety is found to be:

$$MS = \frac{P_{tu}}{P_{lug}} - 1 = \frac{975}{553} - 1 = \text{(Net Tension)} + \underline{0.76}$$

Transverse Load Check



The bearing area $A_{br} = D \times t$

$$A_{br} = 4.5 \times 1.026 = 4.61 \text{ in.}^2$$

If we assume $A_4 = A_1 = 2.6 \times 1.026 = 2.66$ in.^{2} and $A_2 = A_3 = (4.38 - 2.25)1.026 = 2.18$ in.^{2} the average area is then

$$A_{avg} = \frac{6}{(3/A_1 + 1/A_2 + 1/A_3 + 1/A_4)}$$

$$= 6/2.421 = 2.48 \text{ in.}^2$$

The ratio of average area to bearing area is

$$\frac{A_{avg}}{A_{BRG}} = \frac{2.48}{4.61} = 0.539$$

from reference 1 $K_{bru} = 0.76$ and $K_{try} = 0.68$

$$P'_{tru} = K_{bru} A_{br} F_{tu} x = 0.76 \times 4.61 \times 230 = 808 \text{ K}$$

$$P'_{try} = K_{try} A_{br} F_{ty} y = 0.68 \times 4.61 \times 215 = 674 \text{ K}$$

and

$$P_{lug} = 0.6 \times P_{tot} = 0.6 \times 922 = 533 \text{ K/lug}$$

The margin of safety is then

$$MS \frac{P'_{tru}}{P_{lug}} - 1 = \frac{805}{553} - 1 = \text{(Trans. Shear)} + \underline{0.45}$$

FATIGUE AND FRACTURE MECHANICS ANALYSIS

Each of the candidate fittings for the lower cost by substituting steel for titanium (LOCOSST) final analysis phase was subjected to fatigue and fracture mechanics analyses to assure that the predicted life under the design spectrum loading would meet the fatigue design requirements of MIL-A-8866A and the damage tolerance requirements of MIL-A-83444 per the LOCOSST program Statement of Work, paragraph 4.2.1. Simply stated, the fatigue requirement is to insure that the design will not initiate a fatigue crack in four lifetimes of predicted service usage, and the fracture mechanics (crack growth) requirement is to insure that an undetected flaw in the material will not grow to critical size within two design service lifetimes.

The emphasis of the damage tolerance analysis is in the calculation of subcritical flaw growth. The life requirement must be obtained between the specified initial flaw size and the critical flaw size defined by limit or maximum spectrum load. (Refer to MIL-A-83444.) The assumed initial flaw size is determined by the assumed location of the flaw, and the life requirement to the critical length is a function of the assumed inspectability level of the structure. For all analyses done in this phase, it was assumed that the structure would be classified as "in-service noninspectable," requiring the capability of sustaining two design service lifetimes of slow crack growth before failure.

The analytical crack growth prediction methodology employed to calculate subcritical flaw growth is based on the principles of linear elastic fracture mechanics. Rockwell computer program, EFFGRO, was used for performing the crack growth predictions. EFFGRO utilizes a specialized integration routine where an initial crack size, a_i, is chosen and the crack growth rate, da/dN, is integrated to yield the relationship between "a" and "N" for the given stress spectrum. The influence of stresses in the compression region on crack growth rate are taken into consideration.

The fatigue crack growth rate equations used in EFFGRO are the following Paris-type equations with the addition of Walker's stress ratio correction index, m, and the exponent, q, which accounts for the influence of compression stresses on crack growth.

When R, the stress ratio, ≥ 0, $\frac{da}{dN} = C \left[\frac{\Delta K}{(1-R)^{1-m}}\right]^n$

and when $R<0$, $\frac{da}{dN} = C \left[(1-R)^q K_{max}\right]^n$

where c, m, and n are experimentally determined constants from tests at positive stress ratios and q is determined from negative R tests, ΔK is the stress intensity factor range, and K_{max} is the maximum stress intensity value for a given cycle.

MATERIAL PROPERTIES USED IN THE ANALYSIS

The fatigue stress/cycle life (S/N) data and the fatigue crack growth rate (da/dN) data used in the final analysis were generated by the material development test program conducted during this phase. This data is reported in section VI. The modified Goodman diagrams were coded on punched cards for use in an automated fatigue life prediction program which employs Miner's rule of linear cumulative damage for the life predictions.

The Walker equation coefficients used in the crack growth analyses were determined from a best fit straightline through the da/dN versus ΔK crack growth data. A 3.5-percent salt water solution was selected as the environment for the crack growth analyses. This is a somewhat conservative choice of design environment, but seems to be more appropriate for the service life of these fittings than either ambient laboratory air or sump tank water.

WING SWEEP ACTUATOR ATTACH FITTING

Four specific sections of the wing sweep actuator attach fitting were analyzed for durability (fatigue) and damage tolerance (crack growth). These sections are identified in figure 8 . The cross sections selected were those identified in the static stress analysis as having the highest stress levels in that member. Stress transfer functions from the static analysis were used to relate the actuator loads to the stresses in each member for each step of the design fatigue spectrum.

For the fatigue analyses, geometric stress concentration factors were determined by conventional fatigue analysis methods. For specific points of reference, the actuator attach lug, point three, has a geometric K_t equal to 2.7 together with an average net section limit load stress of 70 ksi. The diagonal flange, point two, has a relatively high operating limit stress of 130 ksi, but the K_t factor on this unnotched section is less than 1.5. The bolt holes in the attach flange, point one, have a K_t of approximately four, but the operating limit load net section tension stress is less than 80 ksi. The fatigue analyses of each of these points predict lives well in excess of the required four aircraft lifetimes.

For the damage tolerance analyses, crack growth rate predictions were made for the operating stress spectra and with the required assumed initial flaw size per specification MIL-A-83444 to qualify the structure as "slow crack growth." Figure 9 shows the predicted growth rate of an assumed 0.005R initial corner flaw in a 3/4-inch-diameter bolthole in the flange which attaches to the station 932 bulkhead. This small initial flaw size assumption is permitted by the fastener policy clause in MIL-A-83444. Figure 10 shows the predicted growth rate of an assumed 0.125R initial corner flaw in the diagonal flange at station X_f 90. Figure 11 shows

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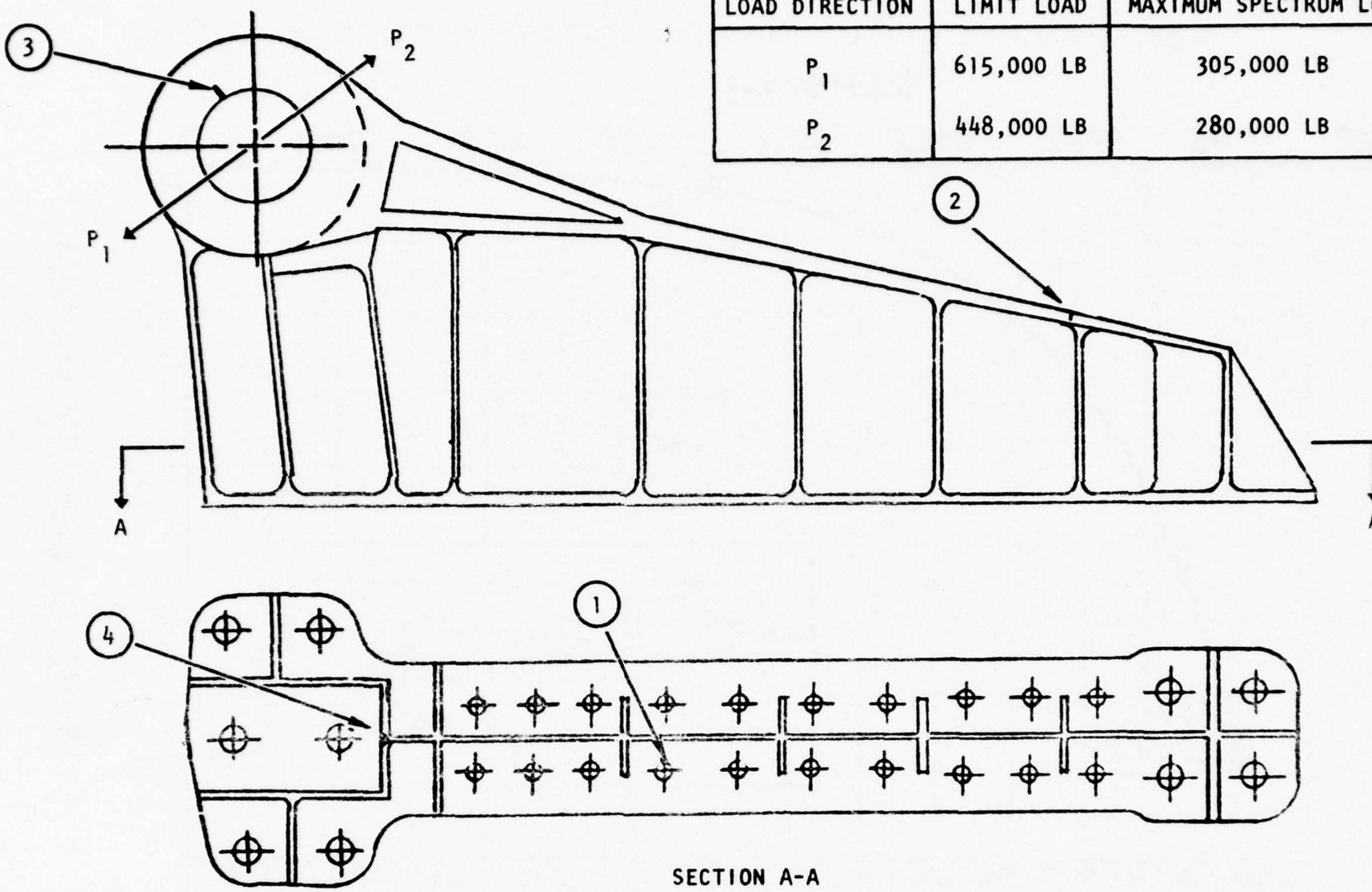


LOAD DIRECTION	LIMIT LOAD	MAXIMUM SPECTRUM LOAD
P_1	615,000 LB	305,000 LB
P_2	448,000 LB	280,000 LB

Figure 8 Areas of Fatigue and Damage Tolerance Analysis - Wing Sweep Actuator Attach Fitting

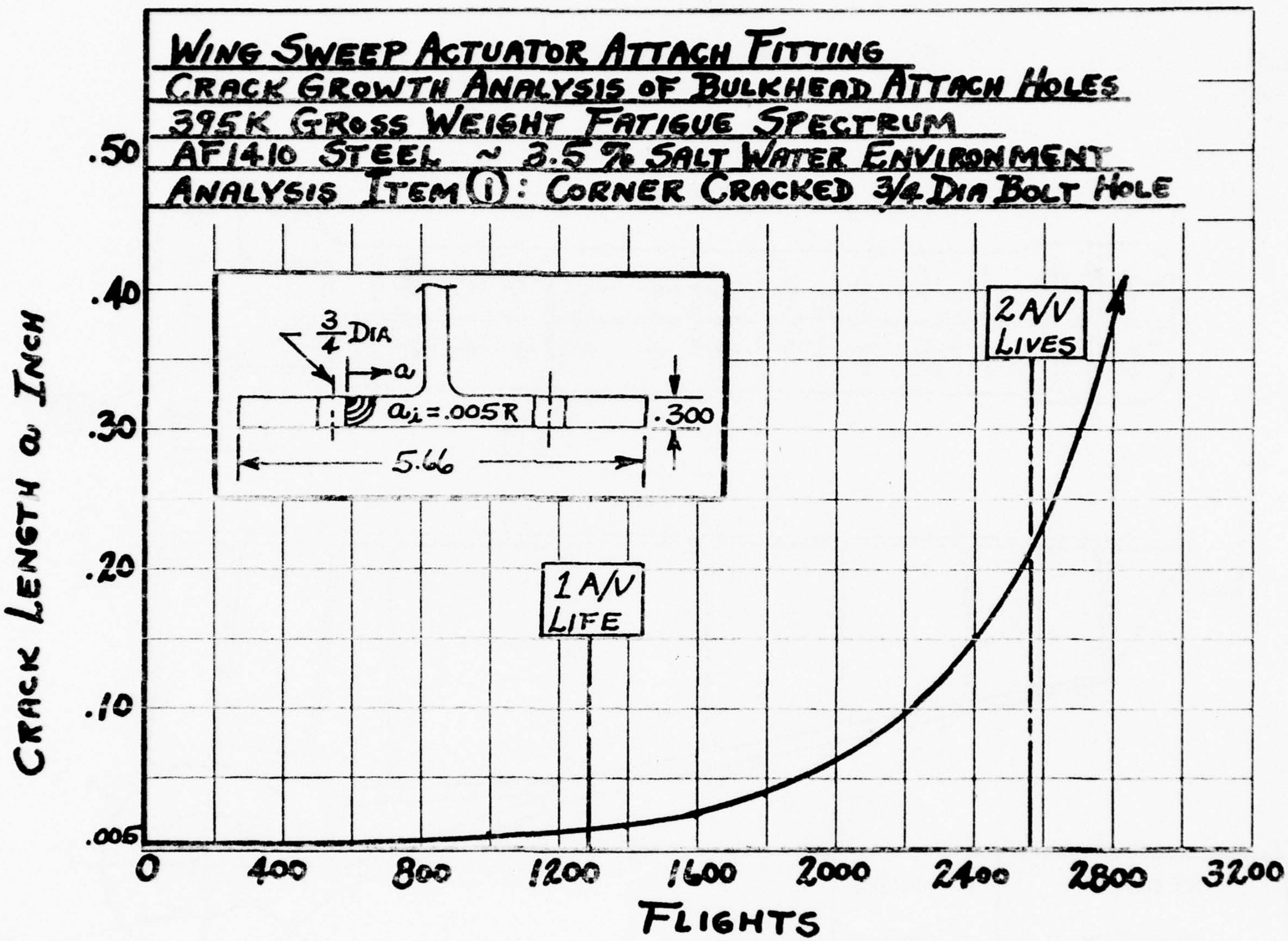


Figure 9 Wing Sweep Actuator Attach Fitting - Item (1) Crack Growth Analysis

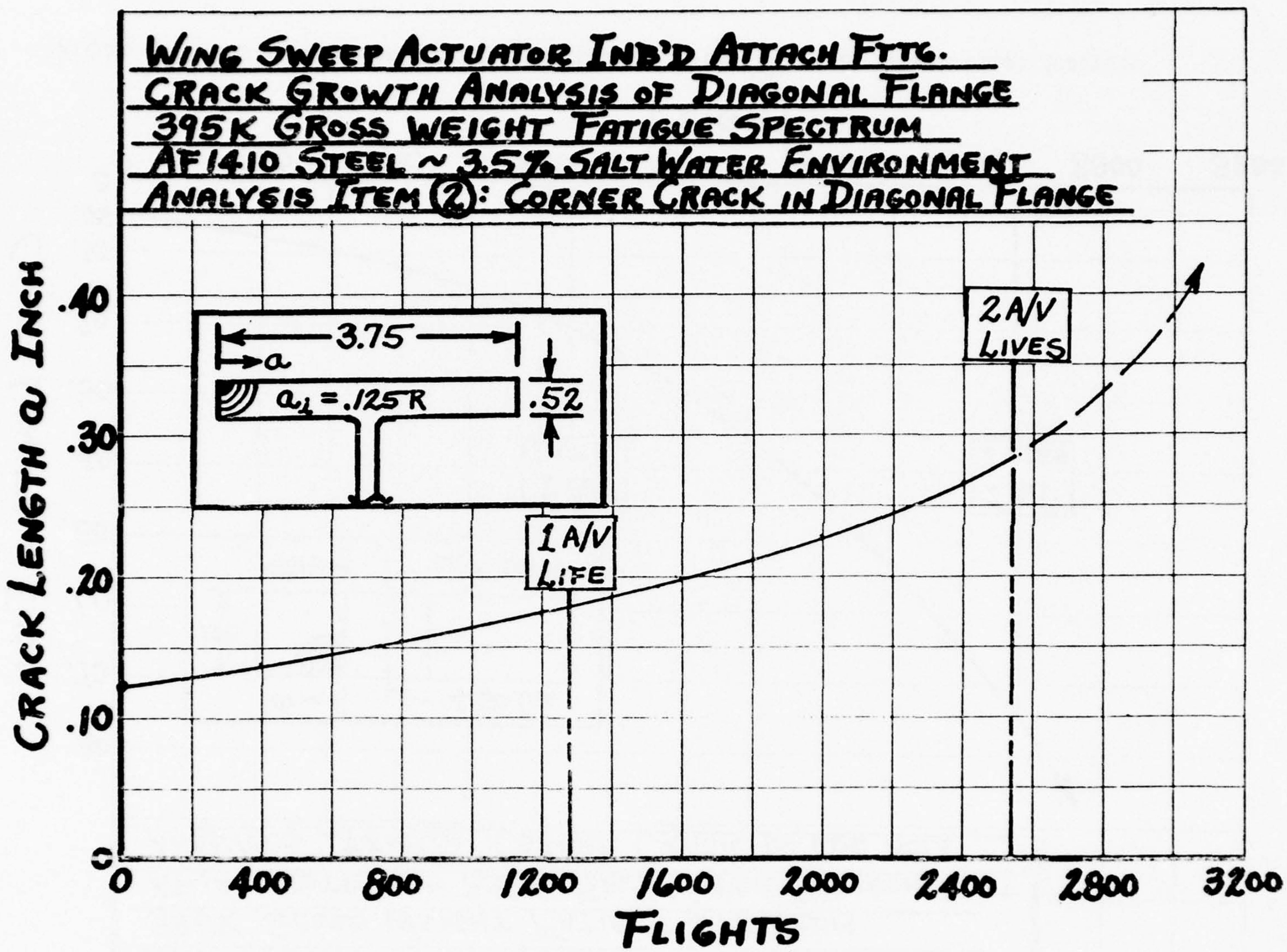


Figure 10 Wing Sweep Actuator Attach Fitting - Item 2 Crack Growth Analysis

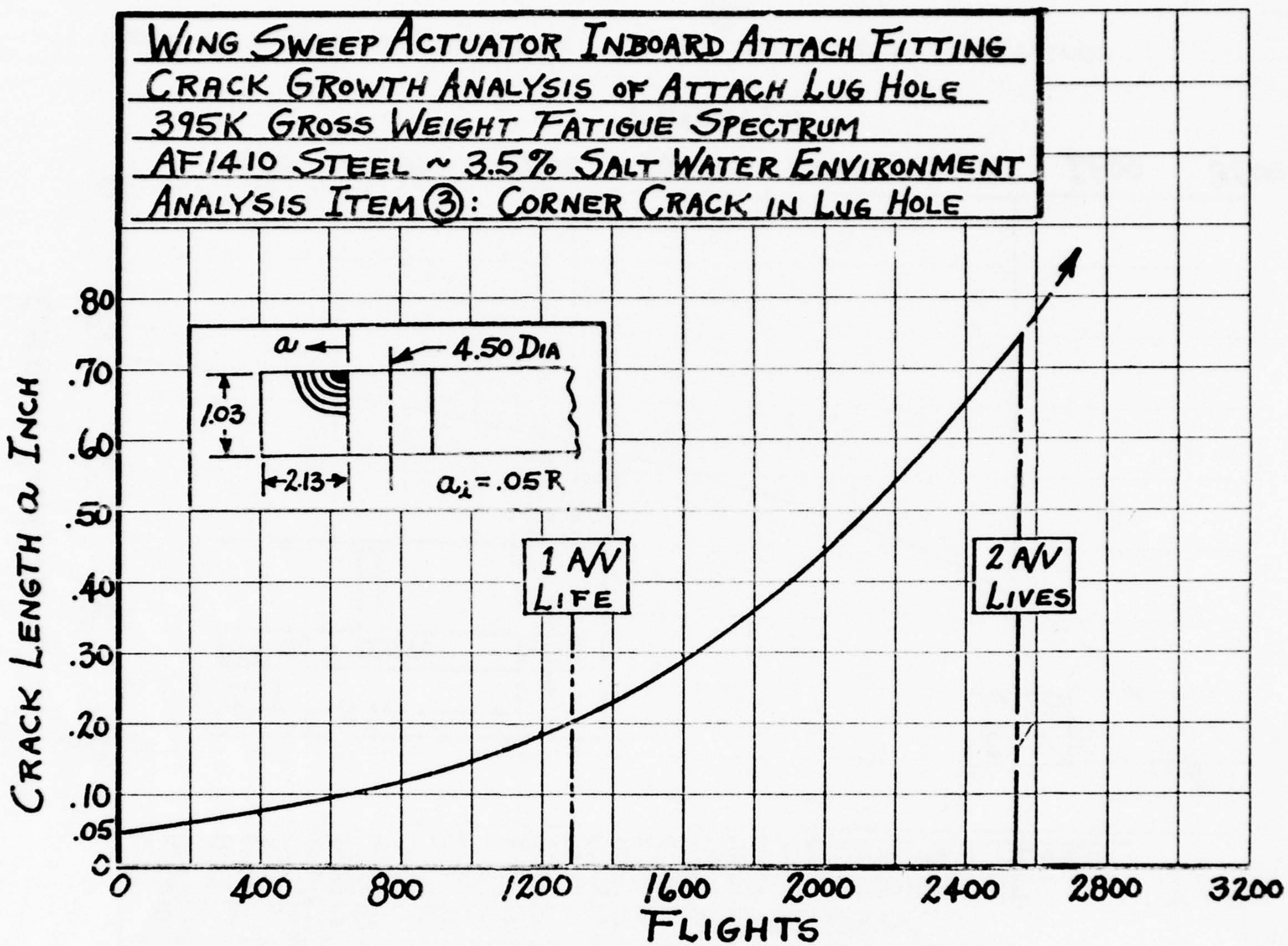


Figure 11 Wing Sweep Actuator Attach Fitting - Item 3 Crack Growth Final Analysis

the predicted crack growth rate of an assumed 0.05R initial corner flaw in the net section of the lug hole. Figure 12 shows the predicted growth rate of an assumed initial 0.125R part-through crack in the 0.300-inch-thick wall of the lug support frame.

All figures show that the predicted crack lives to critical length are in excess of the two aircraft lifetimes required to qualify structure as "slow crack growth" per MIL-A-83444. All fatigue and crack growth analyses were done to the B-1 395,000-pound gross weight operational spectrum.

WING PIVOT INBOARD SHEAR FITTING

The only critical section in fatigue or crack growth on the pivot shear fitting is the actuator attach lug hole. This lug has an outside radius of 1.38 inches, a local thickness of 0.32 inch, and a pin diameter hole of 1.062 inches. The geometric stress concentration factor, K_t, based on these dimensions, is 3.25 at the edge of the hole. Using a quality factor of 1.2, the effective stress concentration factor used for the fatigue analysis was 1.2 X 3.25 = 3.90. An analysis to the operating spectrum stress on the lug net section produces a fatigue life well in excess of the required four lifetimes.

A crack growth analysis was made on this same net section assuming an initial corner flaw of 0.05-inch radius at the edge of the lug hole. Crack growth rate properties used in this analysis were for a 3.5-percent salt solution environment. The life of the assumed initial flaw under the operating stress spectrum exceeds the two lifetime requirements of MIL-A-83444. A plot of the predicted crack growth rate is shown in figure 13 . All other sections on the body of this fitting have less severe stress concentration factors and are not critical in fatigue or crack growth.

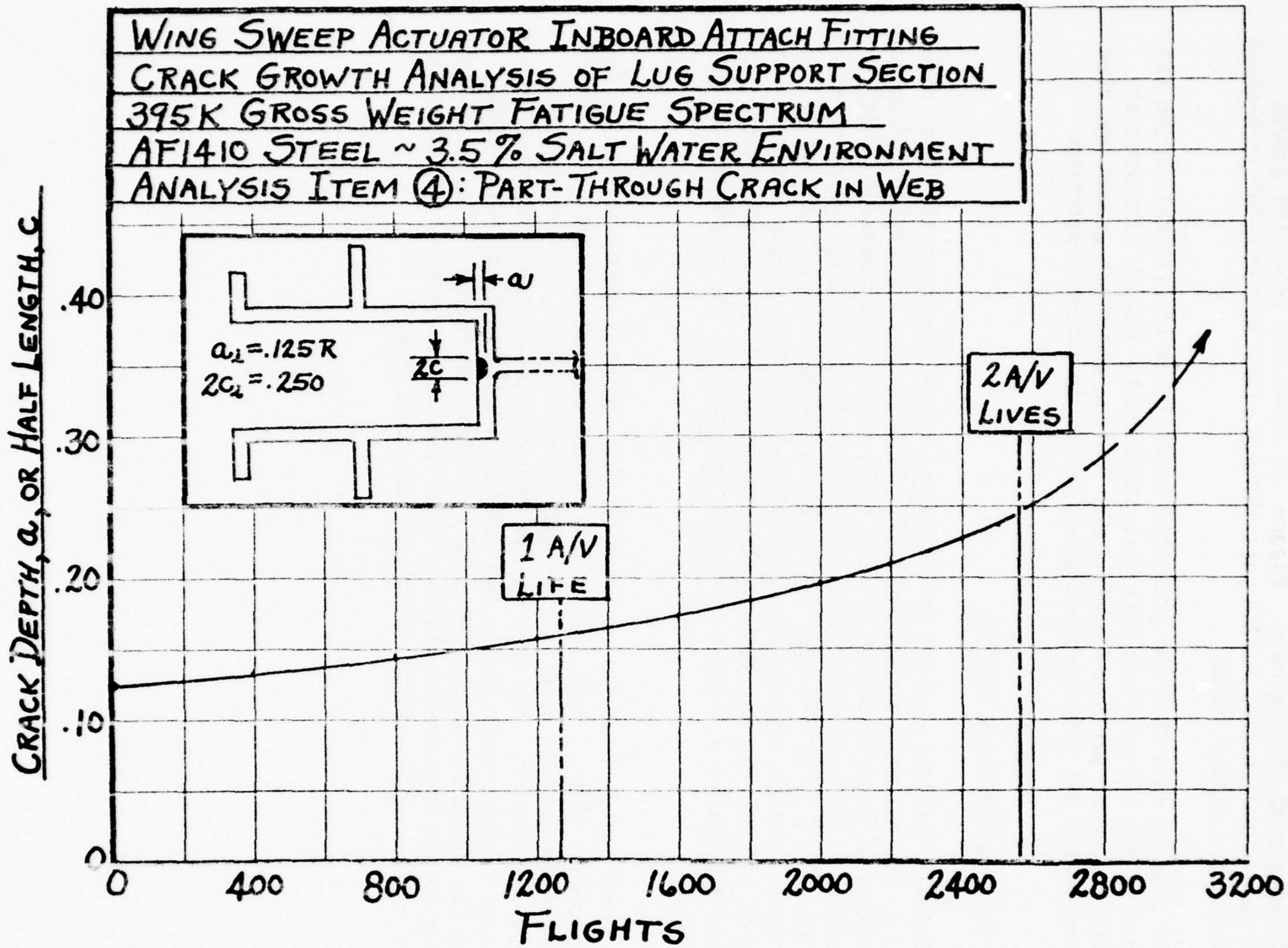


Figure 12 Wing Sweep Actuator Fitting - Item 4 Crack Growth Analysis

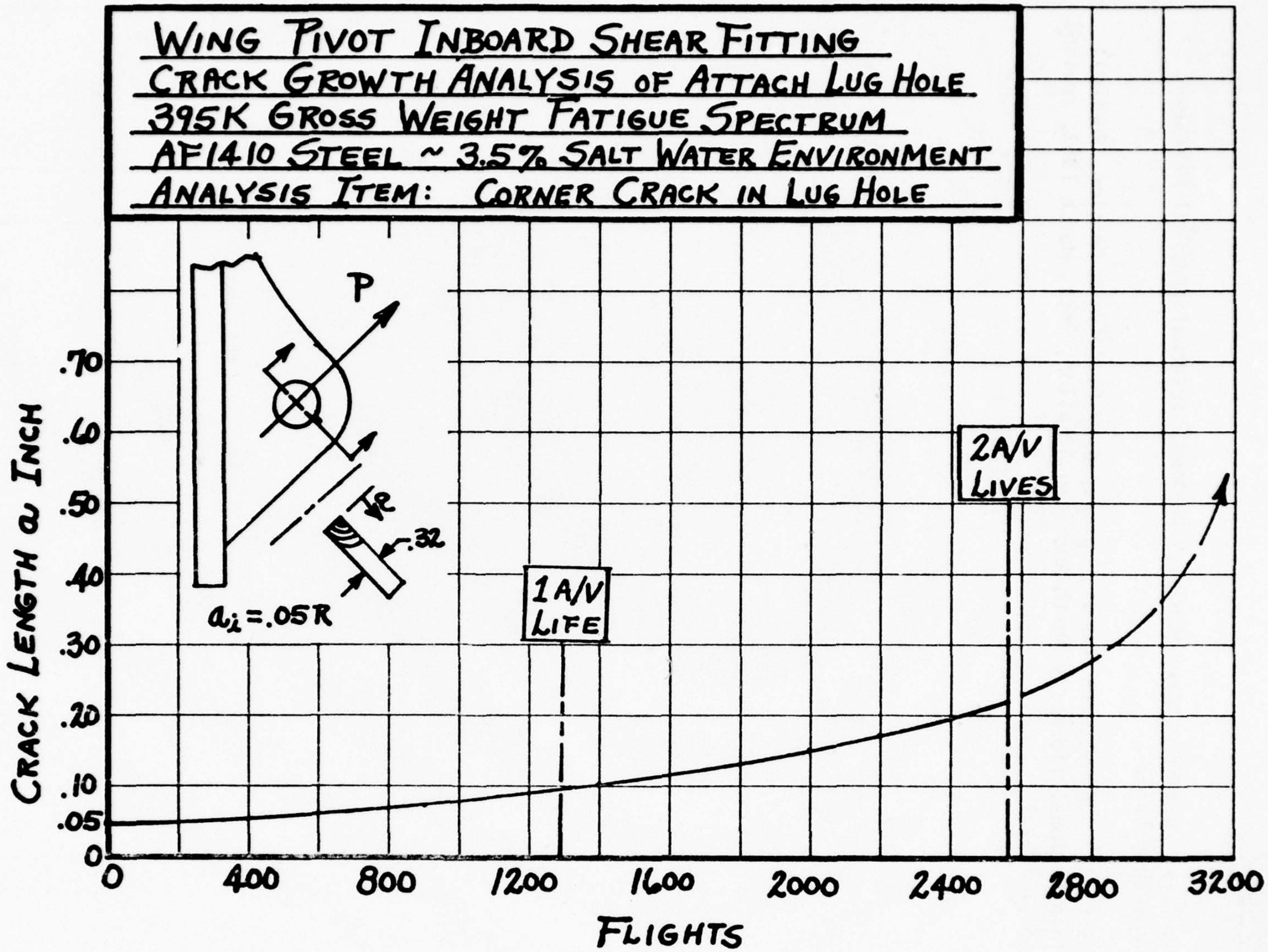


Figure 13. Wing Pivot Inboard Shear Fitting - Lug Hole Crack Growth Analysis

REFERENCES

1. NA-72-1, "B-1 Structures Manual," Rockwell International/B-1 Division, September 1973.

2. NA-52-400, "Structures Manual," prepared by Structures Section, Rockwell International (formerly North American Aviation, Inc), March 1952, revised April 1962.

Section VI

DEVELOPMENT TEST PROGRAM

MATERIAL PROPERTIES

PURPOSE AND OBJECTIVES

Purpose

A series of material property tests were conducted to provide the essential data required for detail design of full-scale components for static and fatigue testing later in the program and for more accurately predicting serviceability, fabrication methods, and production costs using AF 1410 steel.

Test Objectives

Test objectives for this program are as follows:

1. To provide a check of basic mechanical properties of production size heats of the material against those previously obtained on subscale heats.

2. To provide a more complete set of data on basic properties and fatigue characteristics of the parent metal and, in addition, the effects on these properties of selected manufacturing processes which are ordinarily used.

3. To provide mechanical properties, static and dynamic, of butt and fillet welds.

TEST MATERIAL

AF 1410 steel used for all tests was produced by the Universal-Cyclops Specialty Steel Division of Cyclops Corporation under separate Air Force contract. The material was hot-rolled plate in varying thicknesses up to 2 inches. Material received was rolled from VIM-VAR ingots from three separate heats identified by Cyclops as L-3616K13, L-3614K18, and L-3550K20.

Weld wire used for weld specimens is 0.062-diameter AF 1410 steel. It was made by U.S. Welding in Tarzana, California, and identified as heat TLA 260.6. The chemical compositions of this weld wire and the rolled plate heats are given in table 9.

Table 9

CHEMICAL ANALYSIS
AF 1410 STEEL PLATE AND WELD WIRE

	Plate Heat No.		Weld Wire	
Element	L3550K20	L3614K18	L3616K13	TLA2606
C	0.16	0.16	0.17	0.15
Mn	0.07	0.076	0.06	<0.05
Si	0.03	0.03	0.04	<0.01
S	0.002	0.002	0.001	0.005
P	0.005	0.004	0.004	<0.001
Cr	2.06	1.99	1.91	1.90
N_2	0.001	0.0005	0.0002	0.0004
O_2	0.0006	0.0007	0.0003	0.0052
Ni	10.14	10.22	10.10	9.82
Mo	1.02	1.04	0.97	1.00
Co	13.91	13.92	13.98	13.76
Fe	Bal	Bal	Bal	Bal
Al	0.001	0.003	0.003	0.025
Ti	0.004	0.004	0.004	<0.01

SPECIMEN FABRICATION

Material Heat Treatment

The material was received in the as-rolled condition. For the nonwelded specimens, blanks were fully heat treated and aged before machining. For specimens to be welded, the blanks were double-austenitized, machined for weld edge preparation, manual GTAW-welded, aged, then finish-machined. All heat treatment was conducted in ambient air as follows:

- Austenitize 1,650° F - 1 hour, water-quench
- Austenitize 1,500° F - 1 hour, water-quench
- Age 950° F - 5 hours, air-cool

Temperature control was maintained within ±25° F for austenitizing and ±10° F for aging.

Machining and Processing

All machining of specimens was done by regular production methods and machines using cutting tools normally used for high-strength steel. Sharp notches for start of fatigue cracks were machined by electrical discharge. After machining, specimens for manufacturing process effects tests were given a prescribed process by normal manufacturing methods.

Welding

All welding was performed using the manual GTAW process with argon gas shielding. Butt weld joints utilized a double-U groove edge preparation and were made using multiple passes as required.

Fillet welds were made using no edge groove for corner or partial penetration welds. A J-type groove was employed for full penetration welds. All fillet welding was with the minimum number of passes required to achieve the desired fillet size as specified in Rockwell Specification ST0107LA0019.

Radiographic and dye-penetrant inspection was performed on all butt welds and full-penetration fillet welds. The partial penetration fillet welds were dye-penetrant-inspected only (no radiography).

TEST CATEGORIES AND PROCEDURES

Four categories of tests were performed on AF 1410 steel during the development test program:

1. Basic material properties

2. Fracture toughness and fatigue

3. Manufacturing process effects

4. Weld properties

The tests conducted in each of the four categories are defined in tables 10 and 11.

Table 10
STATIC MECHANICAL PROPERTIES TEST MATRIX

Type of Test	Temp	Parent metal					Weldments						Total specimens
		Basic prop.	Manufacturing process effect				Butt welds		Fillet welds				
							0.500 thick		Corner pen.		Full pen. 0.375 thick		
		No. spec & grain dir*	Grinding	Grind + shot peen	Plating	Hydrogen embrittle	Weld	HAZ	0.200 thick	0.375 thick	Asym	Sym	
Tension	-65° F	3L + 2T					14						19
	RT	7L + 4T	2	2	6		14		5	5	5	5	55
	265° F	5L + 3T											8
Sustained notch tension	RT					10							10
Compression	-65° F	3L + 2T											5
	RT	3L + 3T											6
	265° F	3L + 2T											5
Shear	-65° F	3L + 2T											5
	RT	3L + 2T											5
	265° F	3L + 2T											5
Bearing ED = 1.5 dia	-65° F	1L + 1T											2
	RT	1L + 1T											2
	265° F	1L + 1T											2
Bearing ED = 2 dia	-65° F	3L + 2T											5
	RT	3L + 2T											5
	265° F	3L + 2T											5
*L = longitudinal, T = transverse												Total	144

Table 11
FRACTURE TOUGHNESS AND FATIGUE TESTS MATRIX

Type of test	Environment or stress ratio R	Parent metal: Basic prop. — No. of spec & grain dir*	Parent metal: Manufacturing process effects — Grinding	Grind + shot peen	Plating	Weldments: Butt welds 0.500 thick — Weld	HAZ	Fillet welds: Corner pen — 0.200 thick	0.375 thick	Full pen 0.375 thick — Asym	Sym	Total specimens
K_{1c}	-65° F	1RW + 1WR				2	2					6
	RT	2RW + 2WR				2	2					8
	RT - repair					1						1
Charpy	RT					12	12					24
Fatigue unnotched	R = +0.5	6T				11						17
	R = +0.05	8T + 4L	5	5	18	22		8	8	8	9	95
	R = -1.0	6T				11						17
Fatigue K_t = 3.0	R = +0.5	6T										6
	R = +0.05	8T + 4L										12
	R = -1.0	6T										6
Fatigue K_t = 5.0	R = +0.5	6T										6
	R = +0.05	8T + 4L										12
	R = -1.0	6T										6
K_{1scc} RT	STW	7WR + 4RW										11
	3.5% NaCL	5RW				5	5					15
da/dN 0.08R	RT LHA	1WR at 60 cpm										1
		2WR at 1,800 cpm				2	2					6
		1 RW at 1,800 cpm										1
da/dN 0.08R	-65° F LHA	1WR at 1,800 cpm										1
da/dN 0.3R	RT LHA	1 WR at 1,800 cpm										1
da/dN 0.3R	RT 3.5% NaCL	1WR at 60 cpm										1
da/dN 0.08R	RT 3.5% NaCL	2WR at 60 cpm				1						3
	RT STW	1RW at 60 cpm										1
											Total	257

L = longitudinal
T = transverse
LHA = low humidity air
RW = crack prop normal to roll direction
WR = crack prop parallel to roll direction
STW = sump tank water

Basic Material Properties

Tests made for basic material properties on which design allowables were based included tension, compression, shear, and bearing. These tests were run at -65°, 70°, and 265° F. The approach was to utilize the minimum heat-treated strength (S-Type) properties for F_{tu} and F_{ty}, and employing appropriate ratioing techniques and MIL-HDBK-5 guidelines to develop allowables for F_{cy}, F_{su}, and F_{bru}. All test specimen configurations (refer to appendix C, items 1 through 4) and testing techniques for determining these allowables conformed to appropriate American Society for Testing Materials (ASTM) standards.

Fracture Toughness and Fatigue

K_{Ic} values were determined using standard ASTM E399 compact tension specimens (refer to appendix C, item 5). Tests were conducted at -65° F and at room temperature, and the values for RW direction compared with those for WR direction at each test temperature. Testing, data collection, and data interpretation were in accordance with ASTM E399 standard.

Fatigue crack growth rate (da/dN) tests encompassed (1) material directionality; (2) the effect of cyclic rate; (3) the effect of R value; (4) the effect of low temperature; and (5) the effect of both simulated sump tank water and 3.5-percent NaCl solution. Compact tension specimens per ASTM E399 were employed for these tests (refer to appendix C, item 6). Load schedules were selected such that predicted growth rates in the range of 10^{-7} to 10^{-2} inches per cycle could be obtained. Loading of the test specimens was accomplished using constant load, constant amplitude testing parameters. These testing parameters consist of selecting a load range (at a constant ratio of P_{min}/P_{max}) to provide data points within various growth rate regimes of the da/dN curve. Delta K is increased with increasing crack length. Crack growth was monitored throughout the duration of the test by means of a crack opening displacement (COD) gauge. Testing in 3 1/2-percent NaCl was accomplished by "bagging" the specimen in plastic film as shown in figure 14.

Constant amplitude fatigue tests were conducted using the specimens shown in appendix C, items 7 and 8. Stress levels were varied within a group of specimens so that S/N curves could be made. From the various S/N curves generated, constant life diagrams were constructed.

Stress corrosion tests for K_{Iscc} utilized the constant-deflection type specimen shown in appendix C, item 9. Some tests were conducted in simulated sump tank water having the following composition:

$CaCl_2$	68 PPM	$CrCl_3 \cdot 6H_2O$	12 PPM
$CdCl_2$	777 PPM	$CuCl_3 \cdot 2H_2O$	27 PPM

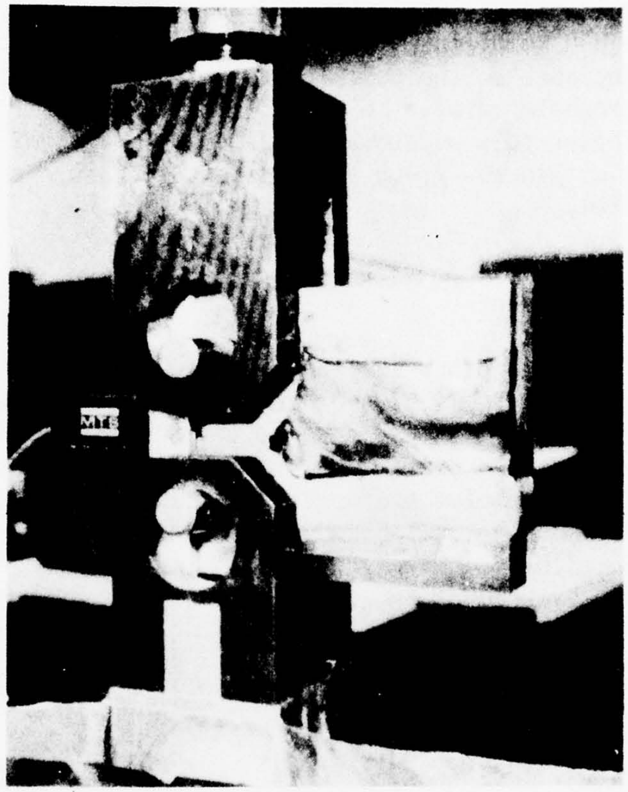


Figure 14 A da/dN Specimen With Crack-Immersed in 3-1/2 Percent NaCl

$MgCl_2$	22 PPM	$FeCl_3$	26 PPM
NaCl	194 PPM	$MnCl_2 \cdot 4H_2O$	27 PPM
$ZnCl_2$	15 PPM	$NiCl_2 \cdot 6H_2O$	6 PPM
$PbCl_2$	28 PPM	Distilled H_2O	Remainder

Other K_{Iscc} tests and five of the da/dN tests were conducted in a 3.5-percent NaCl + H_2O solution. This type of test allows the stress intensity, K, to decrease as the crack grows. Thus, when a specimen is loaded above the K_{Iscc} threshold level, the crack will extend until the stress intensity, K, decreases to a point where the crack no longer grows. Load levels were varied within the group of specimens to insure characterizing the K_{Iscc} of the material.

Manufacturing Process Effects

Certain manufacturing processes are known to adversely affect the properties of high-strength steels. In order to characterize these effects on AF 1410 steel, selected tensile and fatigue tests were performed on specimens subjected to these processes. The processes explored were: (1) grinding, (2) grinding plus shot peening, and (3) Ti-Cad, Electroless Nickel, and Chromium plating, all baked as required by the appropriate specification. Additionally, the hydrogen embrittlement susceptibility of AF 1410 was explored by conducting sustained-load, notched-tension tests on chromium-plated specimens with and without baking. Refer to appendix C, item 10, for specimen configuration.

Weld Properties

A considerable expansion of the weld joint testing portion of the plan has taken place during the initial phase of the contract. First, a number of tests were added for butt weld joints in order to obtain standard allowables for welds using production heats of material and normal welding techniques. Second; a need was foreseen for fillet weld joint data on both full penetration and partial penetration welds; consequently several tests of these types were added. Butt weld tests encompassed tests for tension, fracture toughness, fatigue, and stress-corrosion cracking. Selected tests were conducted with the bead on and the bead off, and with both single and multiple repairs. Fillet welds of both partial and full-penetration type were tested in tension and fatigue only. Full-penetration fillet welds require special machining in most cases to prepare the joint for welding, whereas partial

penetration joints do not, which results in a less expensive weldment. However, partial penetration joints are usually employed only in secondary structure due to concern for fatigue life of such a joint. The test plan was designed to evaluate whether or not the added expense of a full-penetration fillet weld is required in a tough material like AF 1410 steel. Fillet weld specimen configurations are shown in figure 15 .

RESULTS AND DISCUSSION

Parent Metal Properties

Tensile Mechanical Properties

The tensile mechanical properties obtained on 3/4- and 2-inch-thick plates are presented in table 12 and 13 . The 3/4-inch plate was used for characterizing most of the mechanical properties obtained in the program. The 2-inch-thick plate was used to determine K_{1c} values, and limited tensile testing was performed on this thickness in support of the K_{1c} calculations.

The individual test results exhibit very little scatter. The effect of increasing the test temperature is to decrease the F_{tu} and F_{ty} without an attendant change in ductility. Lowering the test temperature to -65° F resulted in an increase in F_{tu} and F_{ty}, with no significant change in the ductility parameters. The results obtained with the two thicknesses were comparable, and no anisotropy was observed.

Compressive Yield

The compression test results are shown in table 14 . The compressive yield strengths are slightly higher than the tensile yield strength values measured on the same thickness of plate; the greatest increase in compressive yield over tensile yield occurs at -65° F. A minor degree of anisotropy, approximately 4 percent, can be observed in the -65° F data.

Shear Tests

The results obtained for the ultimate shear strength, F_{su}, are shown in table 15 . Again, the material exhibited isotropic behavior at all three test temperatures. The effect of temperature on the F_{su} average is similar to that observed for the tensile properties.

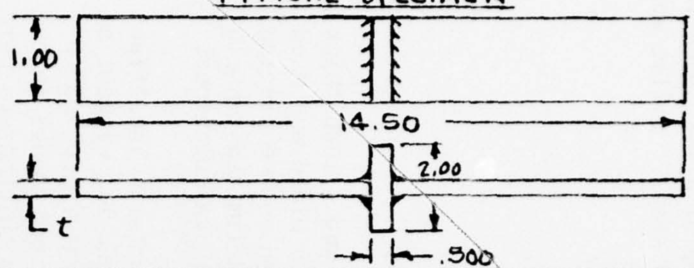
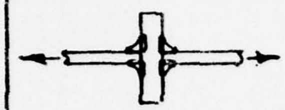
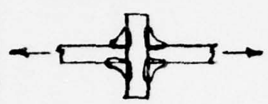
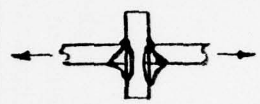
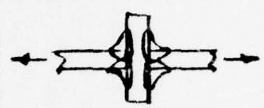
CONDITIONS: 1. ROOM TEMPERATURE 2. MANUAL GAS TUNGSTEN-ARC WELD 3. POST WELD AGE 950°F, 5 HRS. 4. TRANSVERSE GRAIN DIRECTION 5. INSPECTION BY X-RAY AND PENETRANT		TYPICAL SPECIMEN  	
		STATIC TENSILE	CONST. AMPLITUDE FATIGUE
TYPE I - THIN WEB CORNER PENETRATION t = .20		5 TESTS	8 TESTS
TYPE II - THICK WEB CORNER PENETRATION t = .375		5	8
TYPE III - THICK WEB FULL PENETRATION t = .375 ASYMMETRICAL		5	8
TYPE IV - THICK WEB FULL PENETRATION t = .375 SYMMETRICAL		5	8
	TOTAL TESTS	20	32

Figure 15 AF1410 Steel Fillet Weld Joint Tests

Table 12

TENSILE TEST RESULTS FOR AF 1410 ALLOY STEEL
THREE-FOURTHS-INCH-THICK PLATE STOCK - UNIVERSAL CYCLOPS
HEAT NO. L3614 K18

Specimen Identification	Specimen Direction	Test Temp ° F	F_{tu} ksi	F_{ty} ksi	% Elong 4D	% Reduction Area
A1LTR-1	Longitudinal	Room temp	250.5	238.2	15.5	69.4
A1LTR-2	Longitudinal	Room temp	248.5	234.6	15.5	68.6
A1LTR-3	Longitudinal	Room temp	248.9	233.7	15.5	68.9
A1LTR-4	Longitudinal	Room temp	246.8	234.0	15.5	68.3
A1LTR-5	Longitudinal	Room temp	245.6	233.3	15.0	68.4
Average			248.1	234.8	15.5	68.7
A1TTR-1	Transverse	Room temp	248.5	234.3	15.0	68.7
A1TTR-2	Transverse	Room temp	247.2	234.1	15.0	69.5
Average			247.8	234.2	15.0	69.1
A1LT2-1	Longitudinal	265° F	232.3	218.6	16.5	70.9
A1LT2-2	Longitudinal	265° F	235.5	221.2	15.5	68.3
A1LT2-3	Longitudinal	265° F	231.1	217.8	15.5	68.9
Average			233.0	219.2	16.0	69.4
A1TT2-1	Transverse	265° F	233.5	218.4	15.0	69.8
A1TT2-2	Transverse	265° F	233.3	218.8	15.0	69.5
Average			233.4	218.6	15.0	69.6
A1LT0-1	Longitudinal	-65° F	252.6	242.6	15.0	66.9
A1LT0-2	Longitudinal	-65° F	260.0	242.6	16.5	67.7
A1LT0-3	Longitudinal	-65° F	258.1	242.9	15.0	68.0
Average			256.9	242.7	15.5	67.5
A1TT0-1	Transverse	-65° F	260.9	242.2	16.0	68.1
A1TT0-2	Transverse	-65° F	255.6	238.0	14.5	69.1
Average			258.2	240.1	15.0	68.6

Table 13

TENSILE TEST RESULTS FOR AF 1410 ALLOY STEEL
2 INCH THICK PLATE STOCK - UNIVERSAL CYCLOPS
HEAT NO. L3550 K20

Specimen Identification	Specimen Direction	Test Temp ° F	F_{tu} ksi	F_{ty} ksi	% Elong 4D	% Reduction Area
A3LTR1	Longitudinal	Room temp	248.5	230.0	16.0	69.3
A3LTR2	Longitudinal	Room temp	247.1	226.9	16.0	71.5
Average			247.8	228.4	16.0	70.4
A3TTR1	Transverse	Room temp	248.6	228.7	16.0	70.2
A3TTR2	Transverse	Room temp	250.6	228.1	16.0	68.2
Average			249.6	228.4	16.0	69.2
A3LT03	Longitudinal	-65° F	264.2	236.7	16.0	69.8
A3LT04	Longitudinal	-65° F	264.2	234.7	16.0	68.5
Average			264.2	235.7	16.0	69.1
A3TT03	Transverse	-65° F	266.6	248.6	16.0	68.5

Table 14

COMPRESSION TEST RESULTS FOR AF 1410 ALLOY STEEL
THREE-FOURTHS-INCH-THICK PLATE STOCK - UNIVERSAL CYCLOPS
HEAT NO. L3614 K18

Specimen Identification	Specimen Direction	Test Temp ° F	F_{cy} ksi
A1LCR-1	Longitudinal	Room temp	248.1
A1LCR-2	Longitudinal	Room temp	249.3
A1LCR-3	Longitudinal	Room temp	247.4
Average			248.3
A1TCR-1	Transverse	Room temp	249.3[1]
A1TCR-2	Transverse	Room temp	248.5
Average			248.9
A1LC2-1	Longitudinal	265° F	232.9
A1LC2-2	Longitudinal	265° F	230.3
A1LC2-3	Longitudinal	265° F	227.2
Average			230.1
A1TC2-1	Transverse	265° F	231.9
A1TC2-2	Transverse	265° F	233.9
Average			232.9
A1LC0-1	Longitudinal	-65° F	262.0
A1LC0-2	Longitudinal	-65° F	262.1
A1LC0-3	Longitudinal	-65° F	263.0
Average			262.4
A1TC0-1	Transverse	-65° F	271.4
A1TC0-2	Transverse	-65° F	273.6
Average			272.5

(1) Extensometer ran out of travel - yield strength extrapolated.

Table 15

SHEAR TEST RESULTS FOR AF 1410 ALLOY STEEL
THREE-FOURTHS-INCH-THICK PLATE STOCK - UNIVERSAL CYCLOPS
HEAT NO. L3614 K18

Specimen Identification	Specimen Direction	Test Temp ° F	F_{su} ksi
A1LSR-1	Longitudinal	Room temp	148.1
A1LSR-2	Longitudinal	Room temp	148.7
A1LSR-3	Longitudinal	Room temp	148.7
Average			148.5
A1TSR-4	Transverse	Room temp	146.9
A1TSR-4[1]	Transverse	Room temp	148.1
A1TSR-5[1]	Transverse	Room temp	150.6
Average			148.5
A1LS2-6	Longitudinal	265° F	139.1
A1LS2-7	Longitudinal	265° F	139.1
A1LS2-8	Longitudinal	265° F	139.7
Average			139.3
A1TS2-9	Transverse	265° F	141.0
A1TS2-10	Transverse	265° F	139.2
Average			140.1
A1LS0-11	Longitudinal	-65° F	155.5
A1LS0-12	Longitudinal	-65° F	158.5
A1LS0-13	Longitudinal	-65° F	158.2
Average			157.4
A1TS0-14	Transverse	-65° F	162.6
A1TS0-15	Transverse	-65° F	161.0
Average			161.8

[1] Shear cutters failed during test.

Bearing Tests

The bearing properties obtained at the two edge distances are tabulated in table 16 . The values show that an edge distance of 1.5 times the hole diameter results in approximately 100 ksi lower bearing ultimate strength than an edge distance of 2.0. Bearing yield values are not as markedly affected by edge distance. With a 2.0 edge distance, the bearing ultimate is nearly twice the ultimate tensile strength.

Fracture Toughness

The K_{Ic} values obtained with the compact tension specimens are shown in table 17 . Again, as with most of the other properties measured, no notable anisotrophy was observed. The effect of lowering the test temperature is rather dramatic, with a 90° F temperature difference resulting in a 20-percent loss in toughness.

All tests passed the ASTM validity requirements. The shape of the crack front (precrack) was not straight, and is illustrated in figure 16 . However, this amount of waviness conforms to the ASTM shape requirements. Variations in precracking procedures were undertaken in an effort to straighten the crack front, but these efforts proved unsuccessful.

Fatigue Tests

The tabulated data are presented in tables 18 , 19 , and 20 for stress concentrations (K_t) of 1.0, 3.0, and 5.0, respectively. These same data are presented as S/N curves in figure17 through 28 .

The S/N curves for unnotched specimens (K_t = 1.0) are shown in figures 17 through 20 . The longitudinal data (figure 6-4) and the transverse data (figure 18) again reveal the lack of any observed anisotrophy, the two curves being coincident with each other. Three stress ratios (R) were utilized in the transverse tests, and this effect is shown for unnotched specimens in figure 29 . As the stress ratio is varied from +0.5 to 0.0 and down to -1.0, the S/N curve which results is lowered as expected. The effect of changing the R value at 10^7 cycles from +0.5 to -1.0 is to reduce the fatigue strength 50-percent.

The effect of stress concentration (K_t) on the S/N curve is shown in figure 30 for the transverse direction at R = +0.05. The fatigue strength is expressed as a percent of the ultimate tensile strength, and was obtained through interpolative plotting of the data obtained for K_t = 1.0, 3.0, and 5.0.

Table 16

BEARING TEST RESULTS FOR AF 1410 ALLOY STEEL
THREE-FOURTHS-INCH-THICK PLATE STOCK - UNIVERSAL CYCLOPS
HEAT NO. L3614 K18

Speciman Identification	Specimen Direction	e/D Ratio	Test Temp ° F	F_{bru} ksi	F_{bry} ksi
A1LB1R-1	Longitudinal	1.5	Room temp	352.9	303.8
A1LB2R-1	Longitudinal	2.0	Room temp	462.4	349.7
A1LB2R-2	Longitudinal	2.0	Room temp	467.9	347.2
A1LB2R-3	Longitudinal	2.0	Room temp	473.9	351.6
Average				468.1	349.5
A1TB1R-1	Transverse	1.5	Room temp	344.9	300.6
A1TB2R-1	Transverse	2.0	Room temp	472.8	350.6
A1TB2R-2	Transverse	2.0	Room temp	471.1	360.4
Average				472.0	355.5
A1LB12-1	Longitudinal	1.5	265° F	344.9	301.9
A1LB22-1	Longitudinal	2.0	265° F	445.8	338.7
A1LB22-2	Longitudinal	2.0	265° F	453.2	339.6
A1LB22-3	Longitudinal	2.0	265° F	451.3	347.4
Average				450.1	341.9
A1TB12-1	Transverse	1.5	265° F	347.8	301.9
A1TB22-1	Transverse	2.0	265° F	460.1	349.4
A1TB22-2	Transverse	2.0	265° F	458.3	350.0
Average				459.2	349.7
A1LB10-1	Longitudinal	1.5	-65° F	377.6	334.9
A1LB20-1	Longitudinal	2.0	-65° F	500.0	380.6
A1LB20-2	Longitudinal	2.0	-65° F	505.2	388.6
A1LB20-3	Longitudinal	2.0	-65° F	499.7	369.3
Average				501.6	379.5
A1TB10-1	Transverse	1.5	-65° F	376.4	321.9
A1TB20-1	Transverse	2.0	-65° F	500.9	385.2
A1TB20-2	Transverse	2.0	-65° F	501.3	359.5
Average				501.1	372.3

Table 17

FRACTURE TOUGHNESS TEST RESULTS FOR AF 1410 ALLOY STEEL
2-INCH-THICK PLATE STOCK - UNIVERSAL CYCLOPS
HEAT NO. L3550 K20

Specimen Identification	Specimen Direction	Test Temp ° F	K_{Ic} (ksi $\sqrt{\text{in.}}$)
A3RWKR1	RW	Room temp	147.8
A3RWKR8	RW	Room temp	131.3
Average			139.5
A3WRKR3	WR	Room temp	141.9
A3WRKR6	WR	Room temp	131.4
Average			136.6
A3RWKR13	RW	-65° F	109.9
A3WRKR11	WR	-65° F	111.1

NOTE: All tests passed ASTM validity requirements.

The fatigue results were also employed to construct modified Goodman diagrams for five stress concentration factors (K_t); these are shown in figures 31 through 35. Inasmuch as no significant difference was noted in the longitudinal and transverse directions, the data were combined to construct the diagrams.

Fatigue Crack Growth Rate (da/dN)

The da/dN results are shown graphically in figures 36 through 45; individual data points are contained in the table of appendix D. The data allow a study of (1) the effect of cyclic rate, (2) test direction, (3) R-factor, (4) corrosive environment, and (5) low temperatures.

The effect of crack direction with respect to the rolling direction can be observed by comparing the results in figure 36 (RW direction) with those in figures 37 and 38 (both W_R direction). As previously noted by static properties, the steel exhibited isotropic behavior; the growth rate in the two test directions was essentially the same.

AD-A046 705 ROCKWELL INTERNATIONAL LOS ANGELES CALIF LOS ANGELE--ETC F/G 1/3
LOWER COST BY SUBSTITUTING STEEL FOR TITANIUM. AF1410 STEEL-DET--ETC(U)
JUN 77 W E ROUTH F33615-75-C-3109
UNCLASSIFIED RI/LAAD-NA-77-217 AFFDL-TR-77-73 NL

2 OF 4
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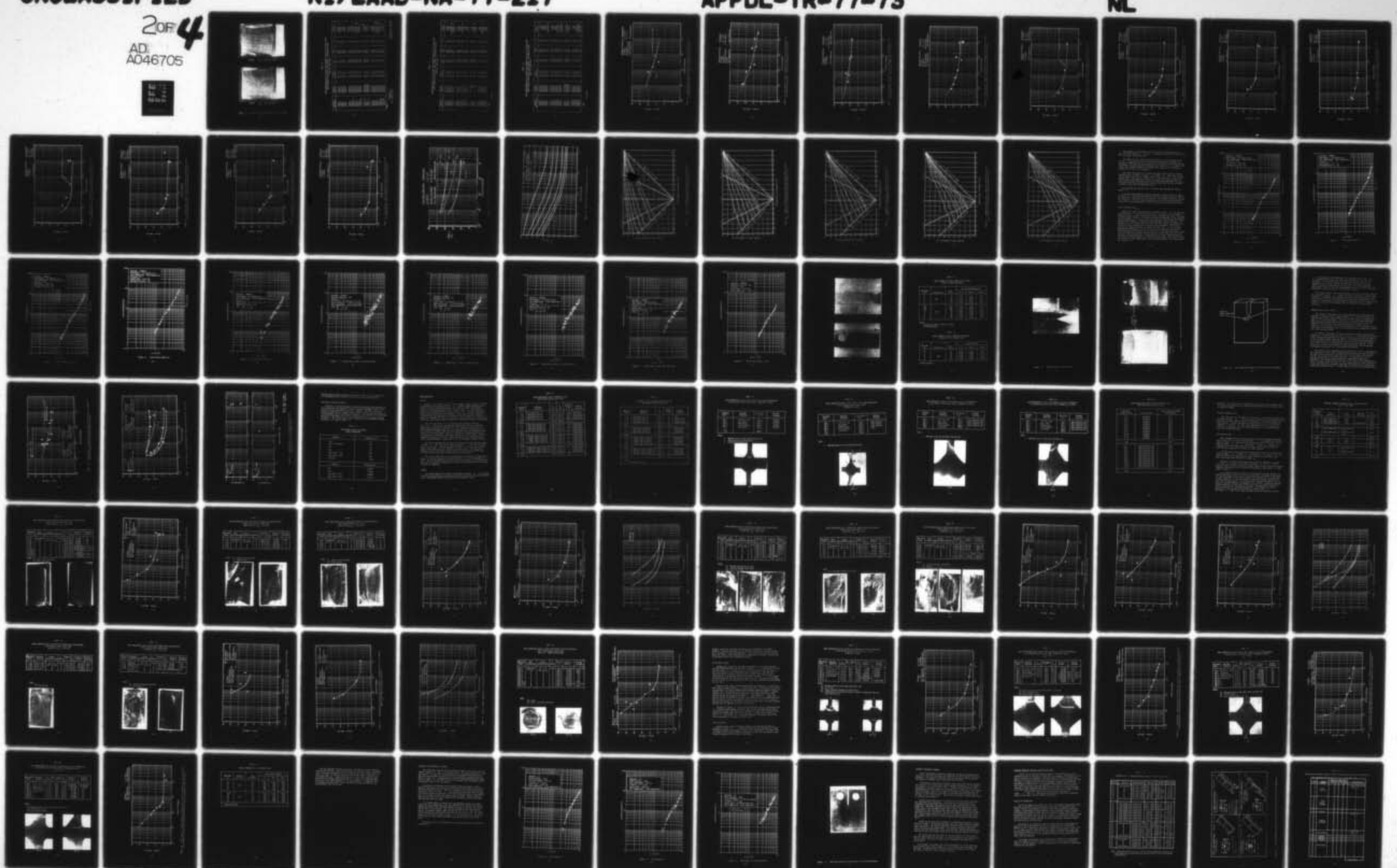
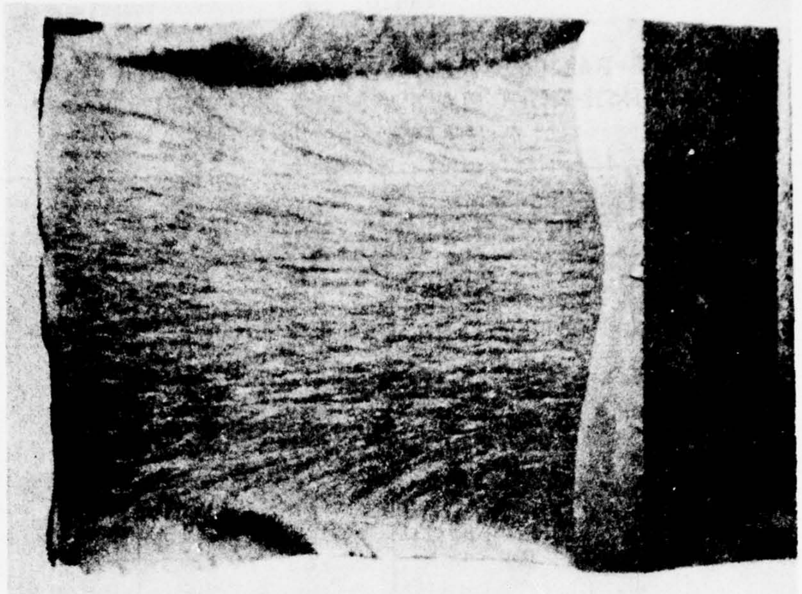
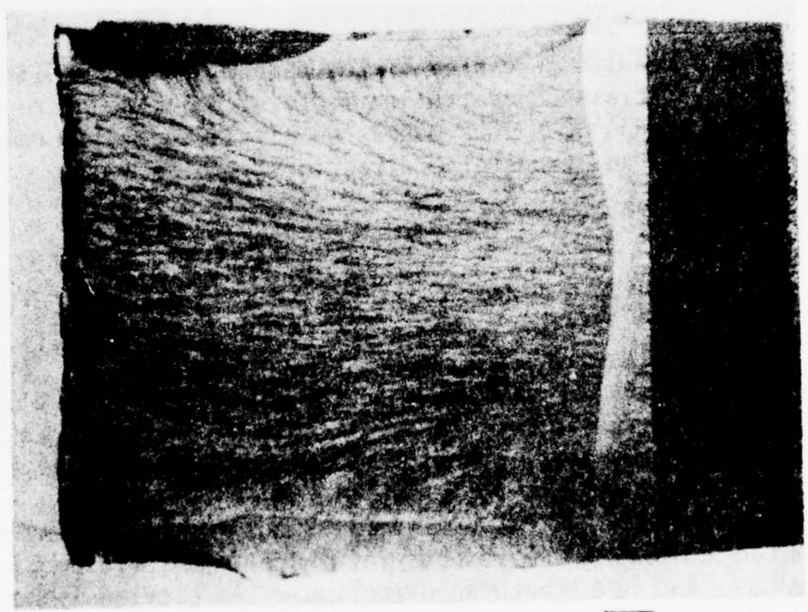
A046705





A3WRKR3 K_{IC} = 141.9 Ksi $\sqrt{in.}$



A3WRKR6 K_{IC} = 131.4 Ksi $\sqrt{in.}$

Figure 16 Fracture Faces of Two Typical K_{Ic} Specimens

Table 18

ROOM TEMPERATURE AXIAL FATIGUE TEST RESULTS FOR AF 1410 ALLOY STEEL
THREE-FOURTHS-INCH-THICK PLATE STOCK - UNIVERSAL CYCLOPS
HEAT NO. L3614 K18

Specimen Identification	Specimen Direction	Stress Concentration	R Factor	Stress ksi	% F_{tu}	Cycles to Failure
A1TFR-1	Transverse	K_t = 1.0	+0.5	210.6	85	22,000
A1TFR-2	Transverse	K_t = 1.0	+0.5	185.8	75	10,300,000 →
A1TFR-3	Transverse	K_t = 1.0	+0.5	198.4	80	678,000
A1TFR-4	Transverse	K_t = 1.0	+0.5	223.0	90	77,000
A1TFR-5	Transverse	K_t = 1.0	+0.5	205.7	83	59,000
A1TFR-6	Transverse	K_t = 1.0	+0.5	190.8	77	883,000
A1TFR-7	Transverse	K_t = 1.0	+0.05	173.5	70	147,000
A1TFR-8	Transverse	K_t = 1.0	+0.05	148.7	60	235,000
A1TFR-9	Transverse	K_t = 1.0	+0.05	198.2	80	78,000
A1TFR-10 (1)	Transverse	K_t = 1.0	+0.05	161.1	65	2,547,000 (1)
A1TFR-11	Transverse	K_t = 1.0	+0.05	223.0	90	12,000
A1TFR-12	Transverse	K_t = 1.0	+0.05	148.7	60	10,000,000 →
A1TFR-13	Transverse	K_t = 1.0	+0.05	123.9	50	24,630,000 →
A1TFR-14	Transverse	K_t = 1.0	+0.05	136.3	55	3,183,000
A1TFR-13 (2)	Transverse	K_t = 1.0	+0.05	210.6	85	13,000 (2)
A1LFR-1 (1)	Longitudinal	K_t = 1.0	+0.05	198.2	80	72,000 (1)
A1LFR-2 (1)	Longitudinal	K_t = 1.0	+0.05	136.3	55	329,000 (1)
A1LFR-3	Longitudinal	K_t = 1.0	+0.05	148.7	60	38,000
A1LFR-4 (1)	Longitudinal	K_t = 1.0	+0.05	173.7	70	155,000 (1)
A1TFR-15	Transverse	K_t = 1.0	-1.0	148.7	60	21,000
A1TFR-16	Transverse	K_t = 1.0	-1.0	123.9	50	158,000
A1TFR-17	Transverse	K_t = 1.0	-1.0	99.1	40	722,000
A1TFR-18	Transverse	K_t = 1.0	-1.0	86.7	35	10,460,000 →
A1TFR-19	Transverse	K_t = 1.0	-1.0	94.2	38	10,000,000 →
A1TFR-20	Transverse	K_t = 1.0	-1.0	111.5	45	10,000,000 →
A1TFR-18 (2)	Transverse	K_t = 1.0	-1.0	136.3	55	53,000 (2)
A1TFR-19 (2)	Transverse	K_t = 1.0	-1.0	161.1	65	10,000 (2)
A1TFR-20 (2)	Transverse	K_t = 1.0	-1.0	131.3	53	1,122,000 (2)

NOTES:

→ No failure
(1) Thread failure
(2) Rerun Specimen

Transverse F_{tu} = 247.8 ksi
Longitudinal F_{tu} = 248.1 ksi

Table 19

ROOM TEMPERATURE AXIAL FATIGUE TEST RESULTS FOR AF 1410 ALLOY STEEL
THREE-FOURTHS-INCH-THICK PLATE STOCK - UNIVERSAL CYCLOPS
HEAT NO. L3614 K18

Specimen Identification	Specimen Direction	Stress Concentration	R Factor	Stress ksi	% F_{tu}	Cycles to Failure
A1TF$_3$R-1	Transverse	$K_t = 3.0$	+0.5	173.5	70	18,000
A1TF$_3$R-2	Transverse	$K_t = 3.0$	+0.5	148.7	60	27,000
A1TF$_3$R-3	Transverse	$K_t = 3.0$	+0.5	123.9	50	76,000
A1TF$_3$R-4	Transverse	$K_t = 3.0$	+0.5	99.1	40	10,260,000 →
A1TF$_3$R-5	Transverse	$K_t = 3.0$	+0.5	111.5	45	12,180,000 →
A1TF$_3$R-6	Transverse	$K_t = 3.0$	+0.5	117.5	47.5	100,000
A1TF$_3$R-7	Transverse	$K_t = 3.0$	+0.05	148.7	60	22,000
A1TF$_3$R-8	Transverse	$K_t = 3.0$	+0.05	123.9	50	14,000
A1TF$_3$R-9	Transverse	$K_t = 3.0$	+0.05	99.1	40	37,000
A1TF$_3$R-10	Transverse	$K_t = 3.0$	+0.05	74.3	30	10,183,000 →
A1TF$_3$R-11	Transverse	$K_t = 3.0$	+0.05	136.3	55	7,000
A1TF$_3$R-12	Transverse	$K_t = 3.0$	+0.05	86.7	35	71,000
A1TF$_3$R-13	Transverse	$K_t = 3.0$	+0.05	161.1	65	4,000
A1TF$_3$R-14	Transverse	$K_t = 3.0$	+0.05	81.8	33	212,000
A1LF$_3$R-1	Longitudinal	$K_t = 3.0$	+0.05	124.1	50	7,000
A1LF$_3$R-2	Longitudinal	$K_t = 3.0$	+0.05	99.2	40	14,000
A1LF$_3$R-3	Longitudinal	$K_t = 3.0$	+0.05	74.4	30	10,484,000 →
A1LF$_3$R-4	Longitudinal	$K_t = 3.0$	+0.05	86.8	35	214,000
A1LF$_3$R-15	Transverse	$K_t = 3.0$	-1.0	99.1	40	5,000
A1LF$_3$R-16	Transverse	$K_t = 3.0$	-1.0	74.3	30	20,000
A1LF$_3$R-17	Transverse	$K_t = 3.0$	-1.0	49.6	20	18,649,000 →
A1LF$_3$R-18	Transverse	$K_t = 3.0$	-1.0	62.0	25	184,000
A1LF$_3$R-19	Transverse	$K_t = 3.0$	-1.0	86.7	35	4,000
A1LF$_3$R-20	Transverse	$K_t = 3.0$	-1.0	57.0	23	90,000

NOTES:

No failure

Table 20

ROOM TEMPERATURE AXIAL FATIGUE TEST RESULTS FOR AF 1410 ALLOY STEEL
THREE-FOURTHS-INCH-THICK PLATE STOCK - UNIVERSAL CYCLOPS
HEAT NO. L3614 K18

Specimen Identification	Specimen Direction	Stress Concentration	R Factor	Stress ksi	% F_{tu}	Cycles to Failure
A1TF$_5$R-1	Transverse	K_t = 5.0	+0.5	148.7	60	7,000
A1TF$_5$R-2	Transverse	K_t = 5.0	+0.5	123.9	50	16,000
A1TF$_5$R-3	Transverse	K_t = 5.0	+0.5	99.1	40	231,000
A1TF$_5$R-4	Transverse	K_t = 5.0	+0.5	74.3	30	57,000
A1TF$_5$R-5	Transverse	K_t = 5.0	+0.5	86.7	35	44,000
A1TF$_5$R-6	Transverse	K_t = 5.0	+0.5	62.0	25	10,000,000 →
A1TF$_5$R-7	Transverse	K_t = 5.0	+0.05	123.9	50	5,000
A1TF$_5$R-8	Transverse	K_t = 5.0	+0.05	99.1	40	10,000
A1TF$_5$R-9	Transverse	K_t = 5.0	+0.05	74.3	30	45,000
A1TF$_5$R-10	Transverse	K_t = 5.0	+0.05	62.0	25	74,000
A1TF$_5$R-11	Transverse	K_t = 5.0	+0.05	49.6	20	10,000,000 →
A1TF$_5$R-12	Transverse	K_t = 5.0	+0.05	86.7	35	11,000
A1TF$_5$R-13	Transverse	K_t = 5.0	+0.05	57.0	23	10,737,000 →
A1TF$_5$R-14	Transverse	K_t = 5.0	+0.05	81.8	33	40,609,000 →
A1LF$_5$R-1	Longitudinal	K_t = 5.0	+0.05	99.2	40	41,000
A1LF$_5$R-2	Longitudinal	K_t = 5.0	+0.05	74.4	30	10,222,000 →
A1LF$_5$R-3	Longitudinal	K_t = 5.0	+0.05	86.8	35	10,025,000
A1LF$_5$R-4	Longitudinal	K_t = 5.0	+0.05	124.1	50	13,000
A1TF$_5$R-15	Transverse	K_t = 5.0	-1.0	99.1	40	4,000
A1TF$_5$R-16	Transverse	K_t = 5.0	-1.0	74.3	30	10,000
A1TF$_5$R-17	Transverse	K_t = 5.0	-1.0	49.6	20	26,000
A1TF$_5$R-18	Transverse	K_t = 5.0	-1.0	24.8	10	11,200,000 →
A1TF$_5$R-19	Transverse	K_t = 5.0	-1.0	37.2	15	10,000,000 →
A1TF$_5$R-20	Transverse	K_t = 5.0	-1.0	62.0	25	4,711,000

NOTES:

No failure

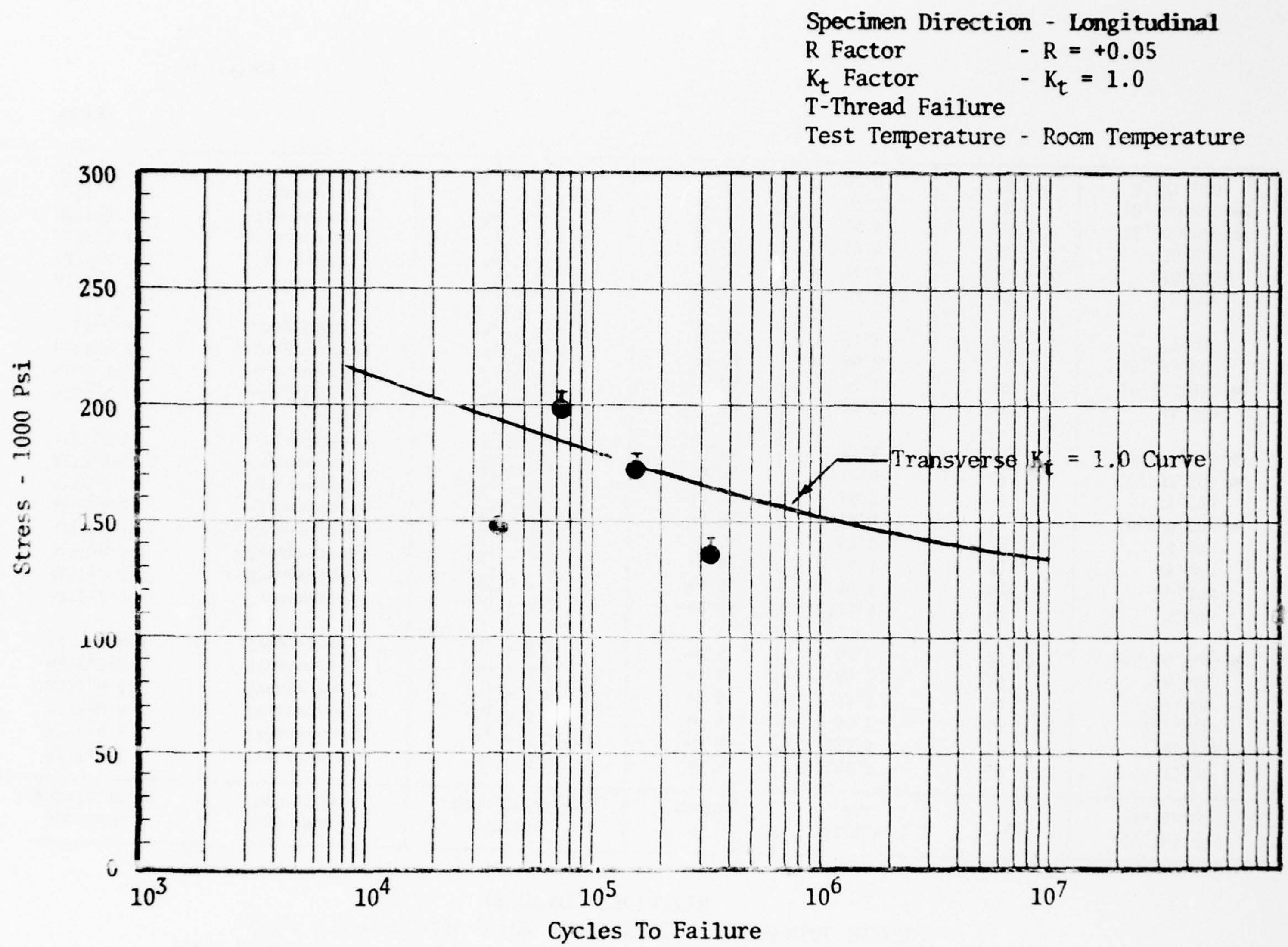


Figure 17 Axial Tension - Tension Fatigue Test Results for AF1410 Alloy Steel 3/4-Inch-Thick Plate Stock - Universal Cyclops Heat No. L3614 K18

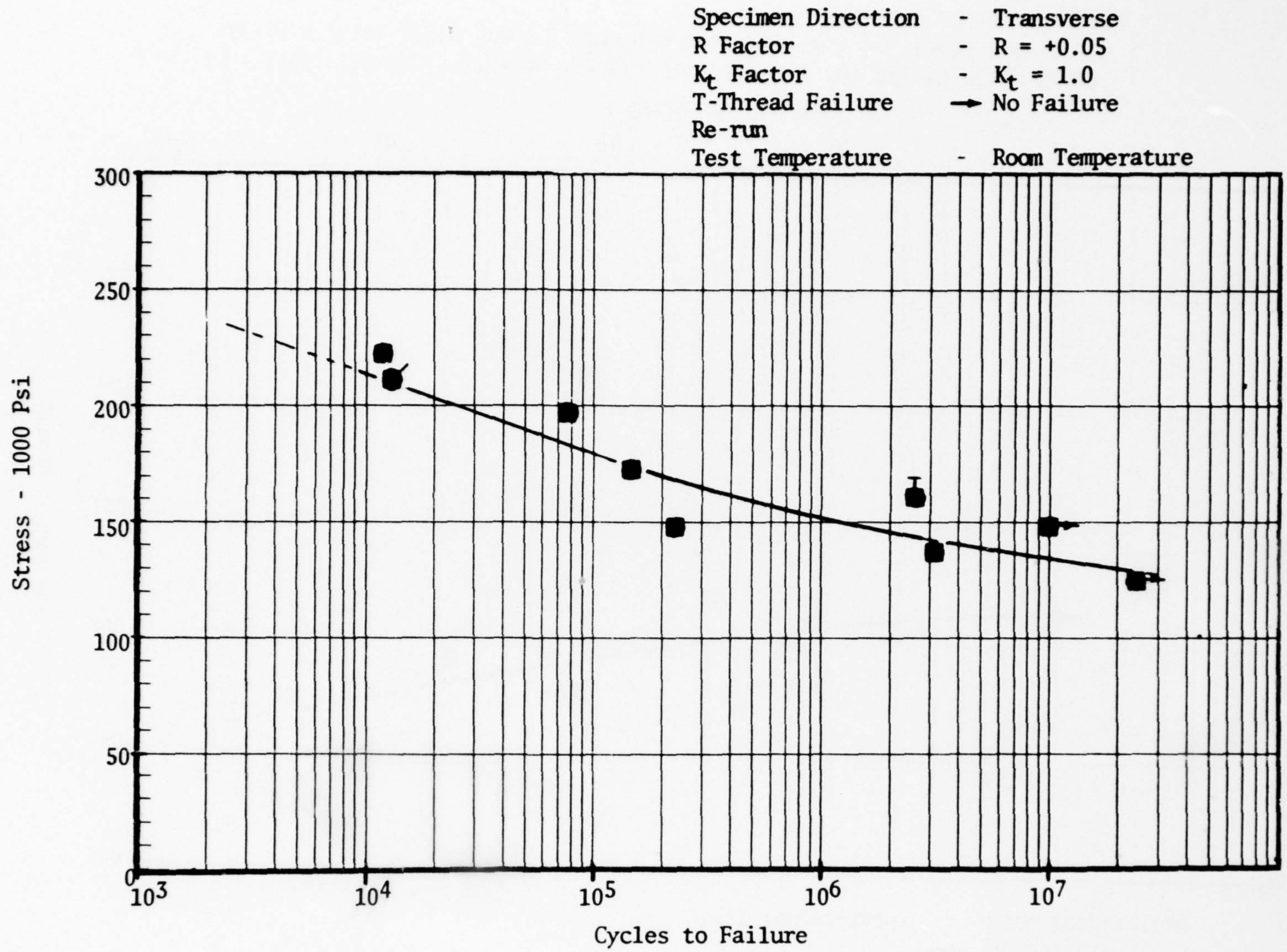


Figure 18 Axial Tension - Tension Fatigue Test Results for AF1410 Alloy Steel 3/4-Inch-Thick Plate Stock - Universal Cyclops Heat No. L3614 K18

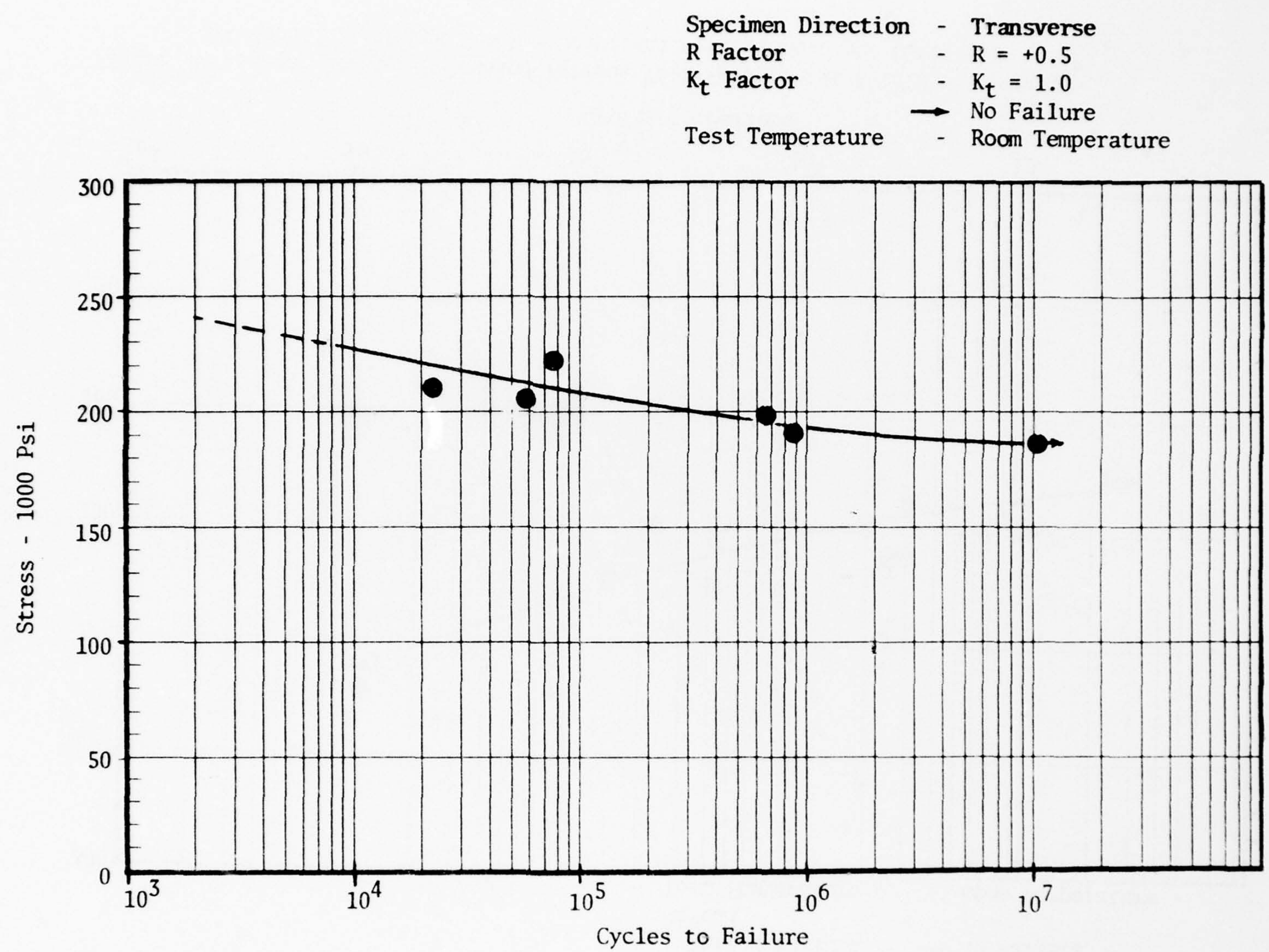


Figure 19 Axial Tension - Tension Fatigue Test Results for AF1410 Alloy Steel 3/4-Inch-Thick Plate Stock - Universal Cyclops Heat No. L3614 K18

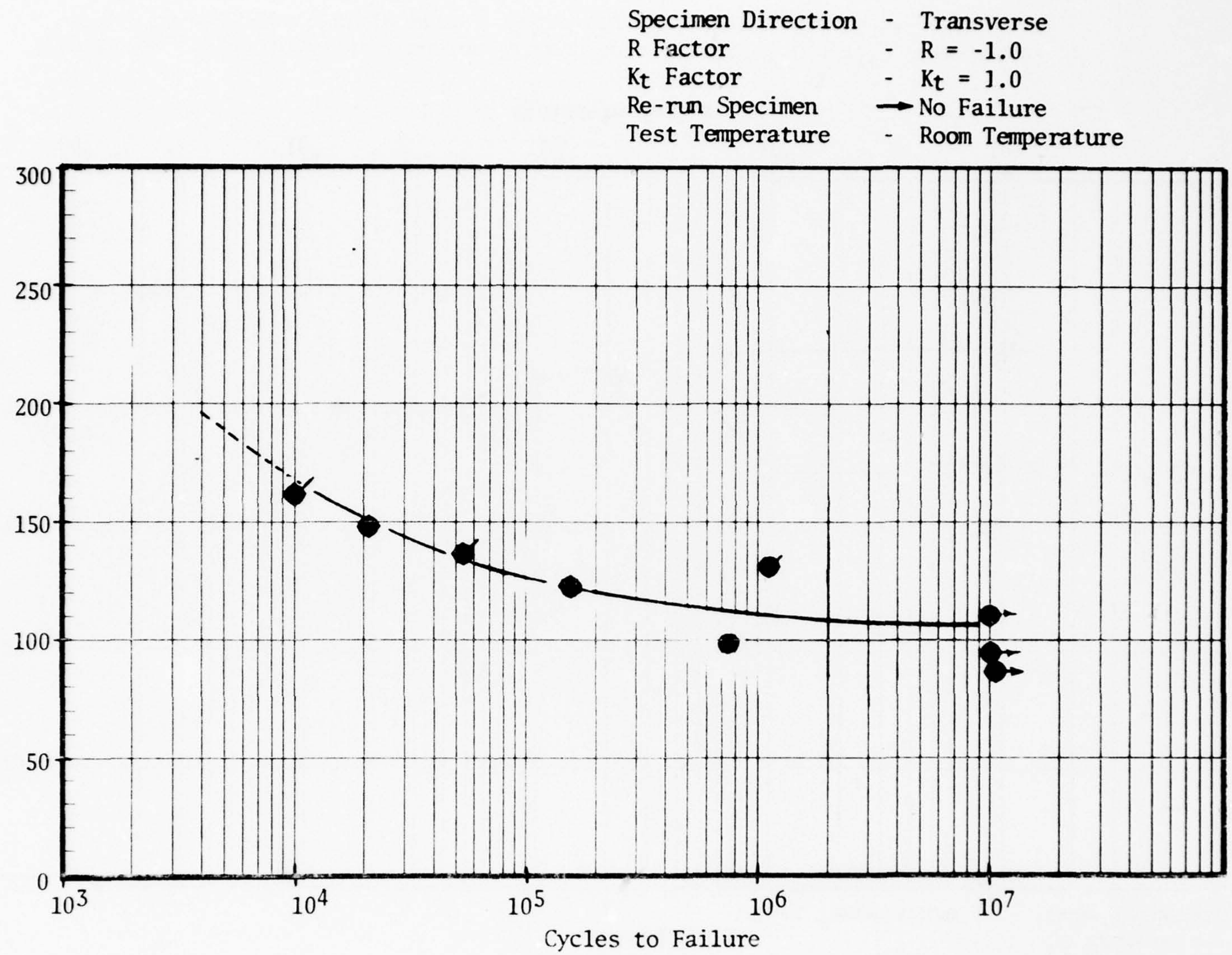


Figure 20 Axial Tension - Compression Fatigue Test Results for AF1410 Alloy Steel 3/4-Inch-Thick Plate Stock - Universal Cyclops Heat No. L3614 K18

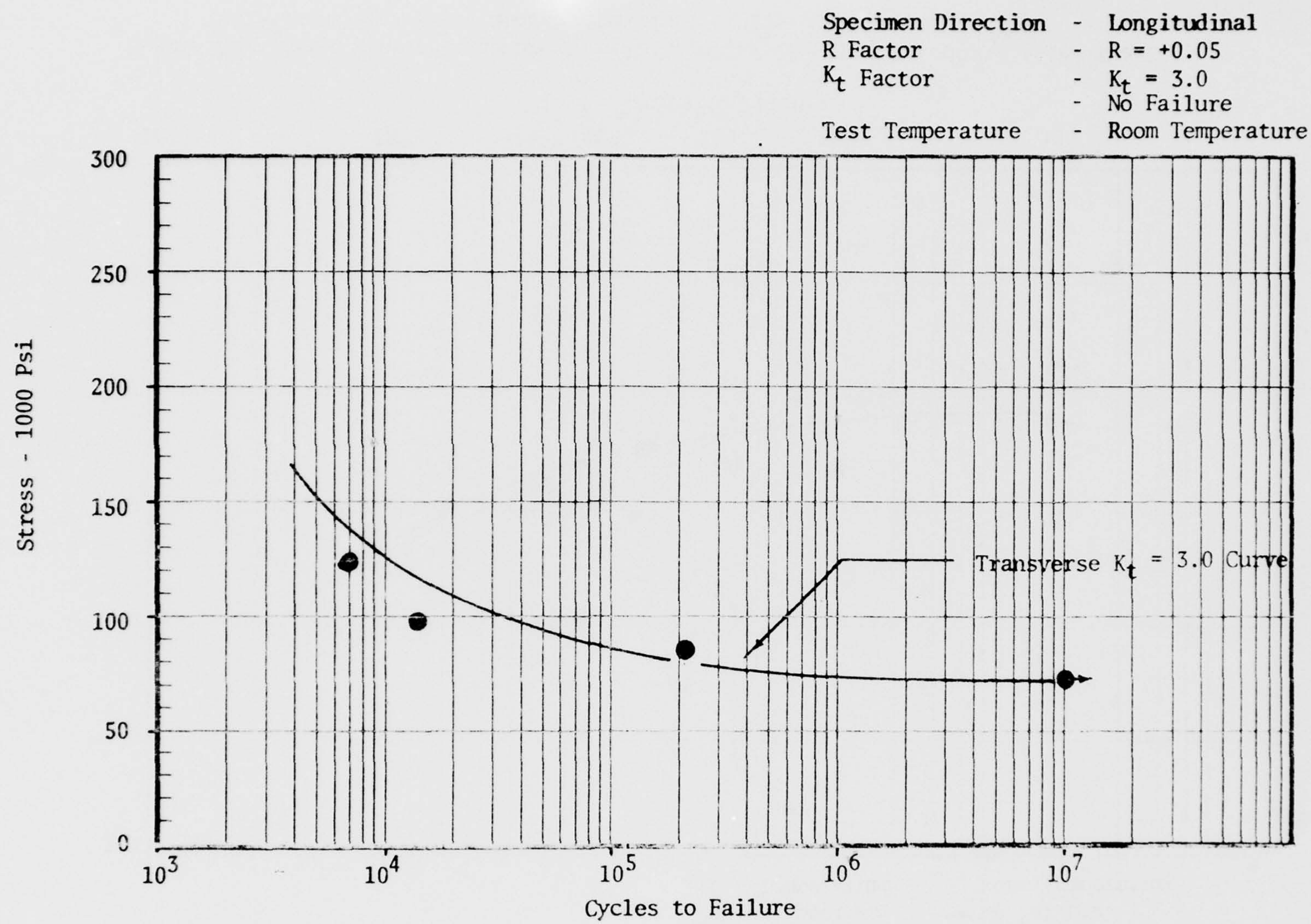


Figure 21 Axial Tension - Tension Fatigue Test Results for AF1410 Alloy Steel 3/4-Inch-Thick Plate Stock - Universal Cyclops Heat No. L3614 K18

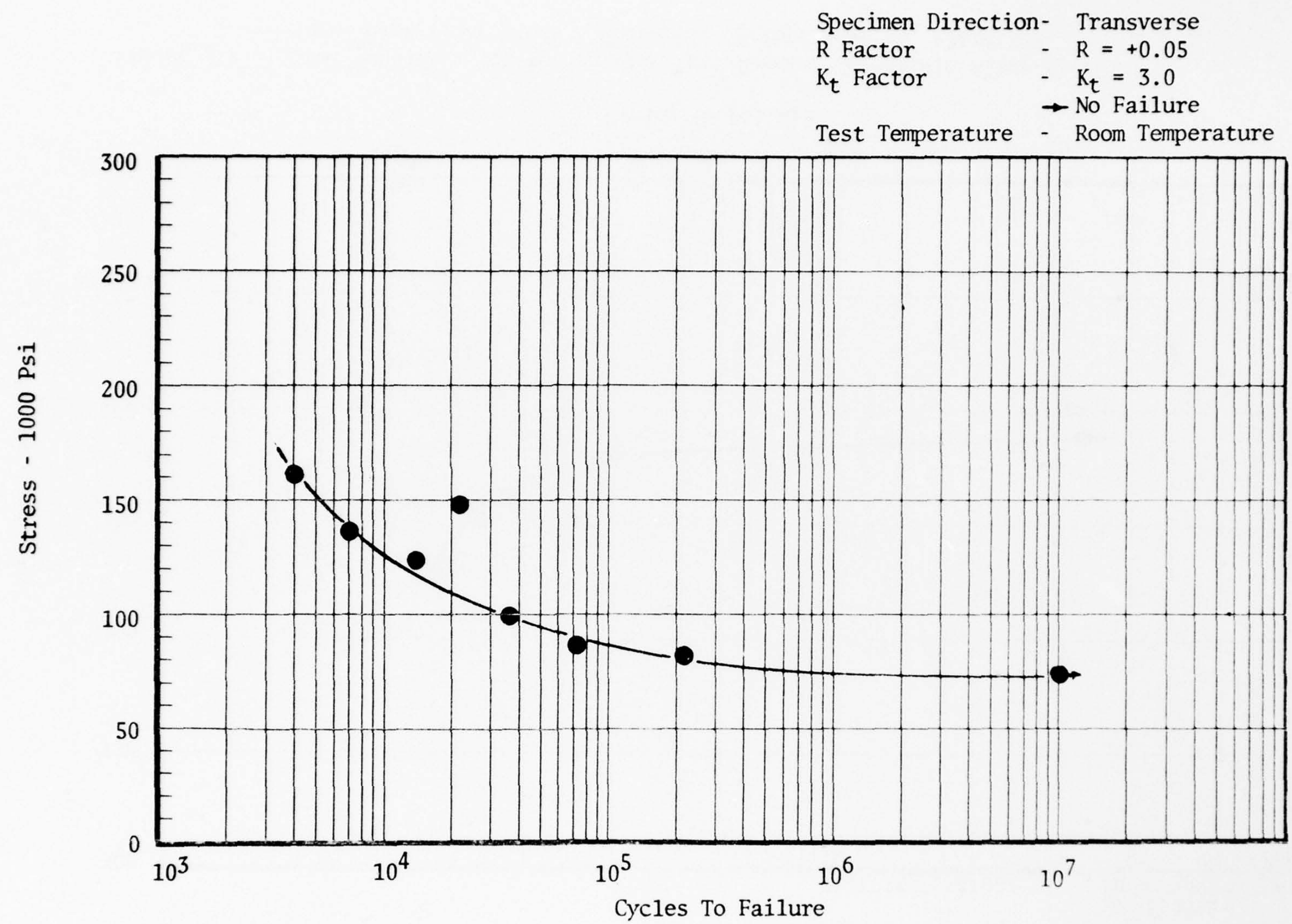


Figure 22 Axial Tension - Tension Fatigue Test Results for AF1410 Alloy Steel 3/4-Inch-Thick Plate Stock - Universal Cyclops Heat No. L3614 K18

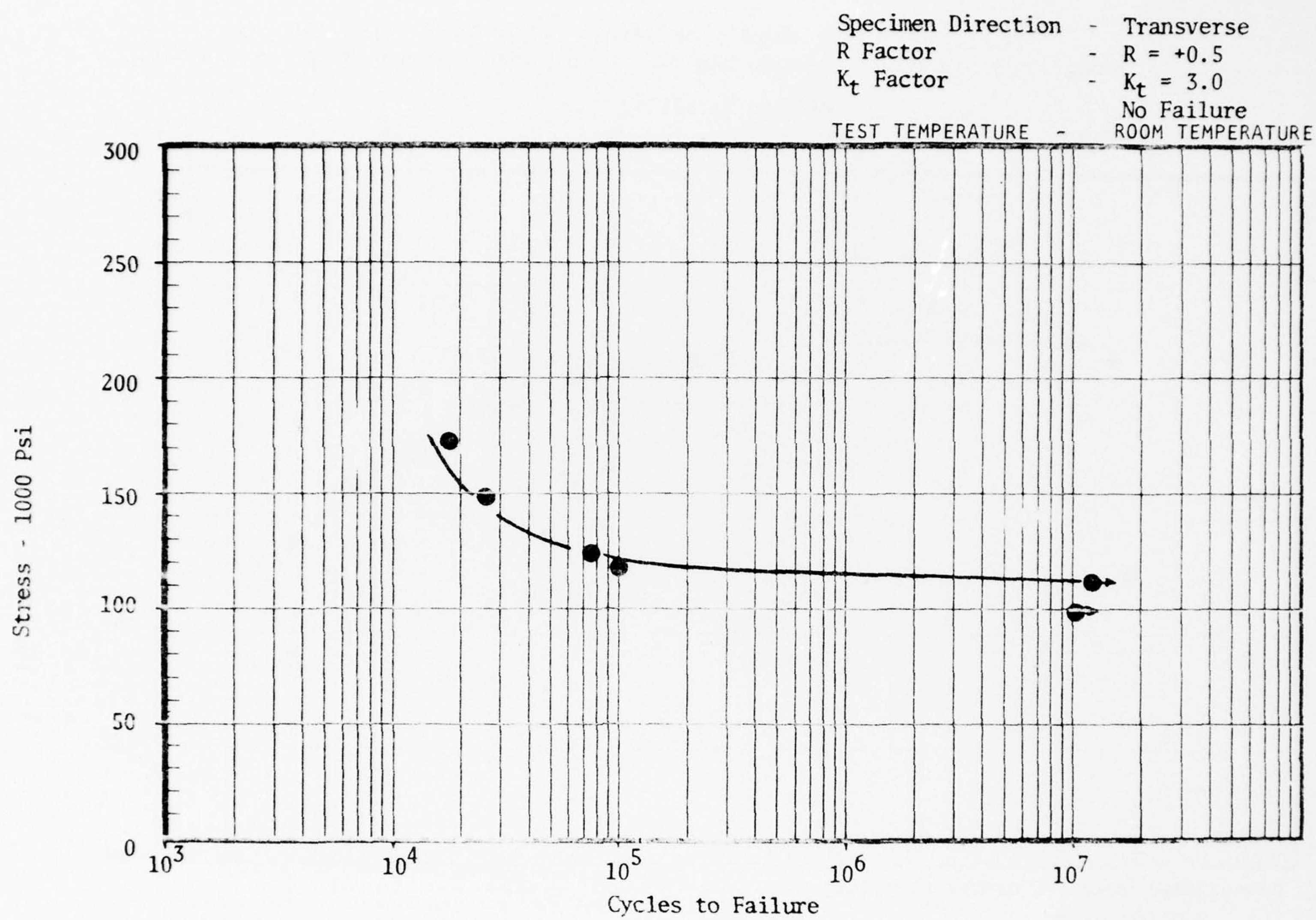


Figure 23 Axial Tension - Tension Fatigue Test Results for AF1410 Alloy Steel 3/4-Inch-Thick Plate Stock - Universal Cyclops Heat No. L3614 K18

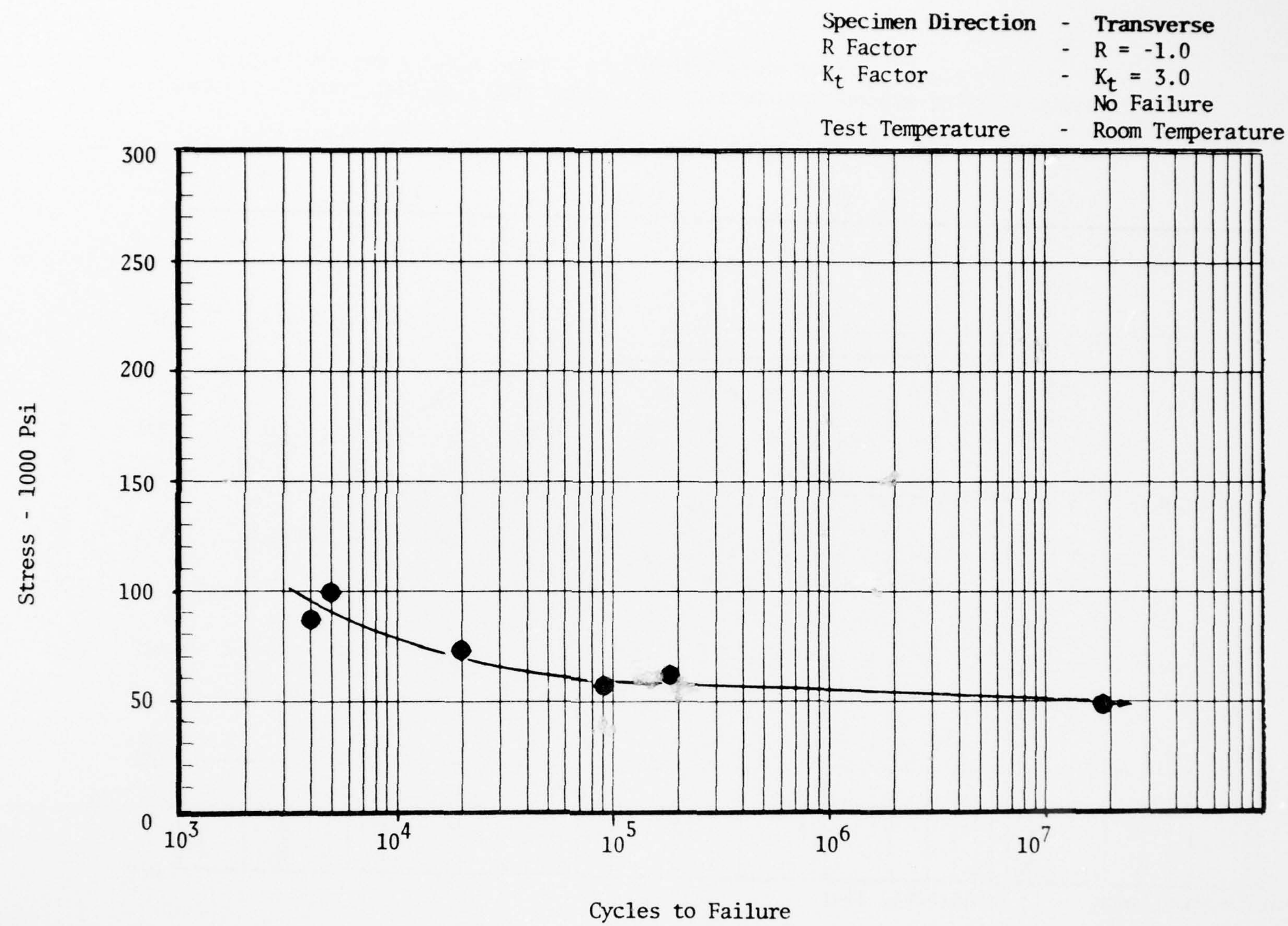


Figure 24 Axial Tension - Compression Fatigue Test Results for AF1410 Alloy Steel 3/4-Inch-Thick Plate Stock - Universal Cyclops Heat No. L3614 K18

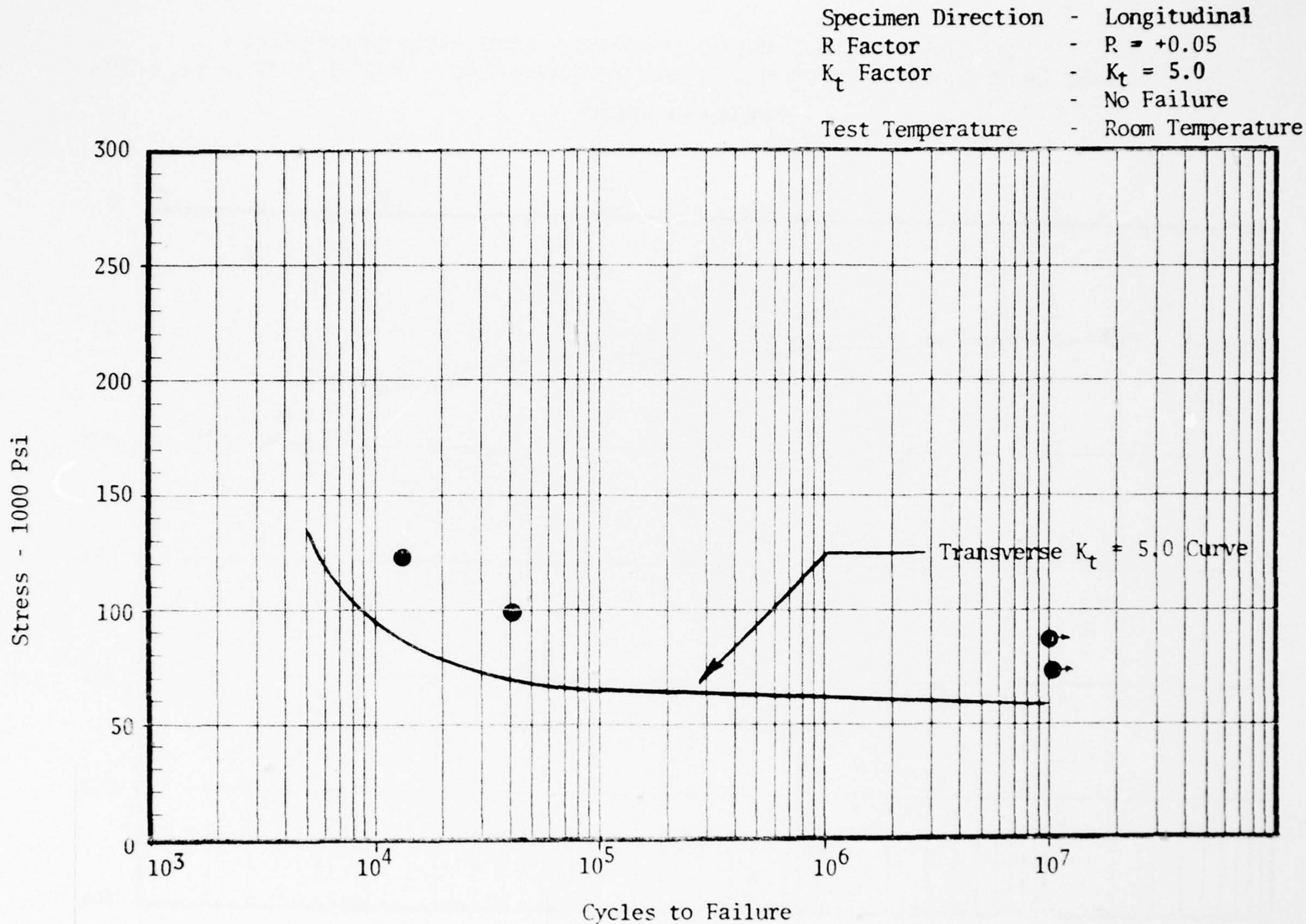


Figure 25 Axial Tension - Tension Fatigue Test Results for AF1410 Alloy Steel 3/4-Inch-Thick Plate Stock - Universal Cyclops Heat No. L3614 K18

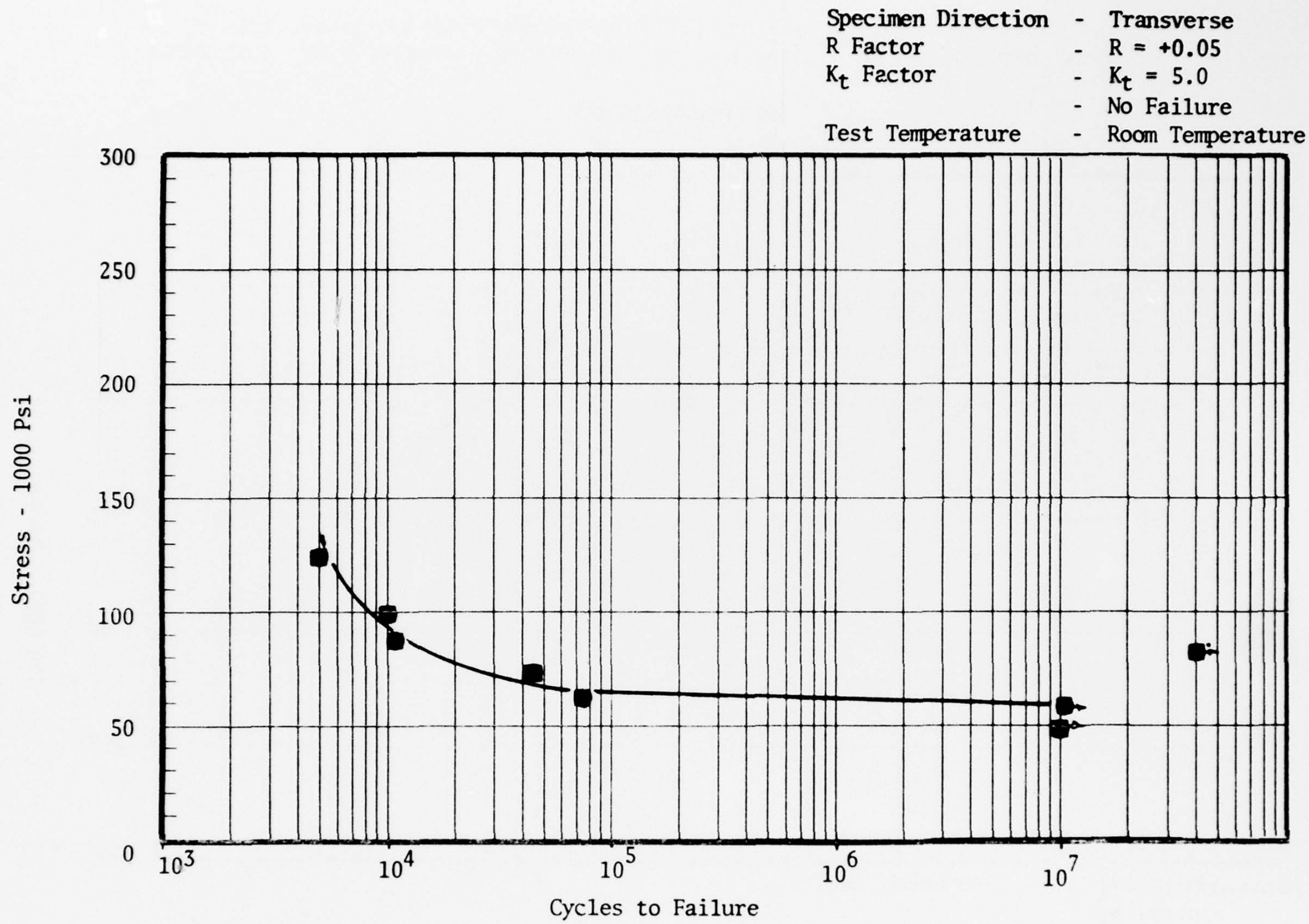


Figure 26 Axial Tension - Tension Fatigue Test Results for AF1410 Alloy Steel 3/4-Inch-Thick Plate Stock - Universal Cyclops Heat No. L3614 K18

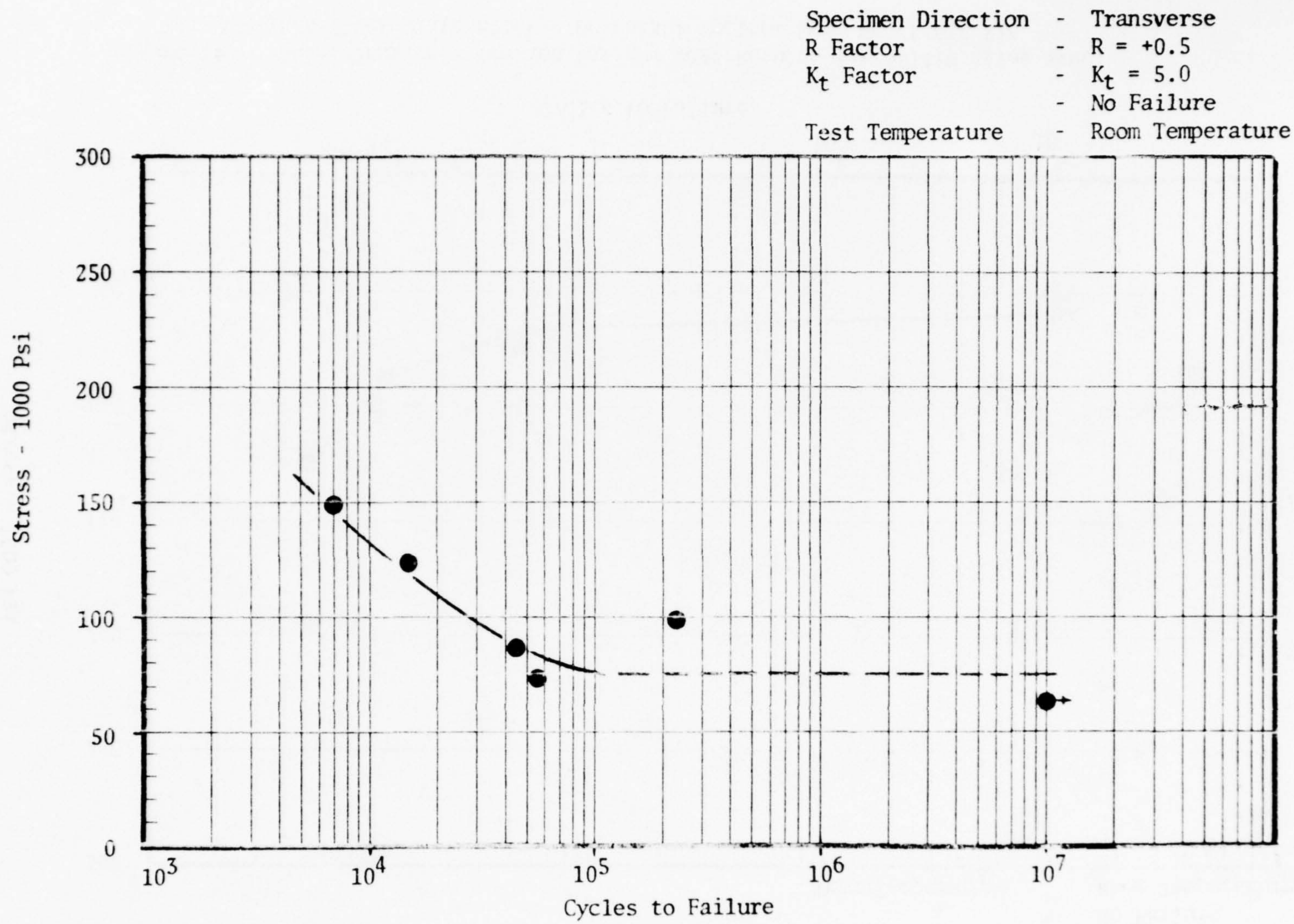


Figure 27 Axial Tension - Tension Fatigue Test Results for AF1410 Alloy Steel 3/4-Inch-Thick Plate Stock - Universal Cyclops Heat No. L3614 K18

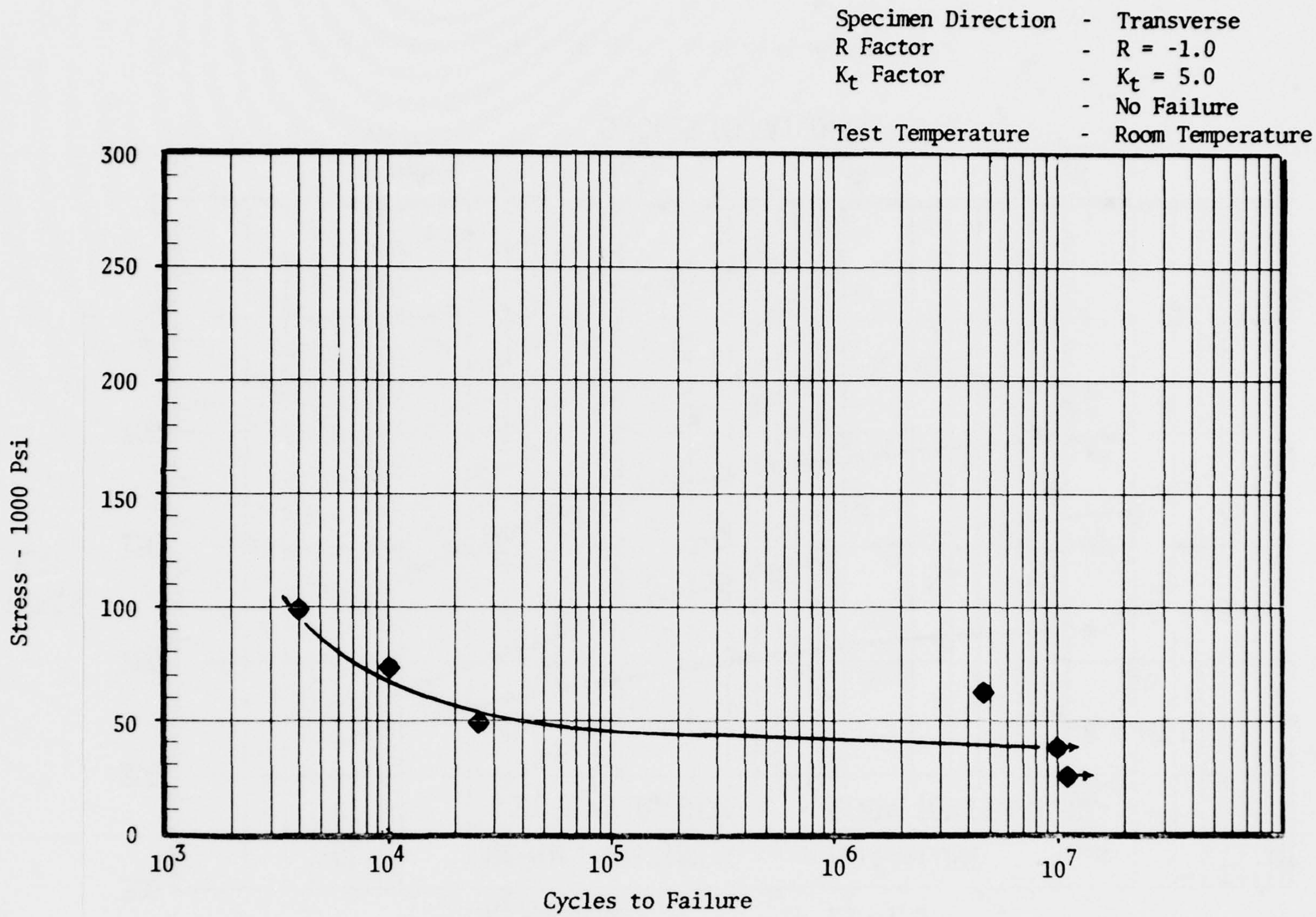


Figure 28 Axial Tension - Tension Fatigue Test Results for AF1410 Alloy Steel 3/4-Inch-Thick Plate Stock - Universal Cyclops Heat No. L3614 K18

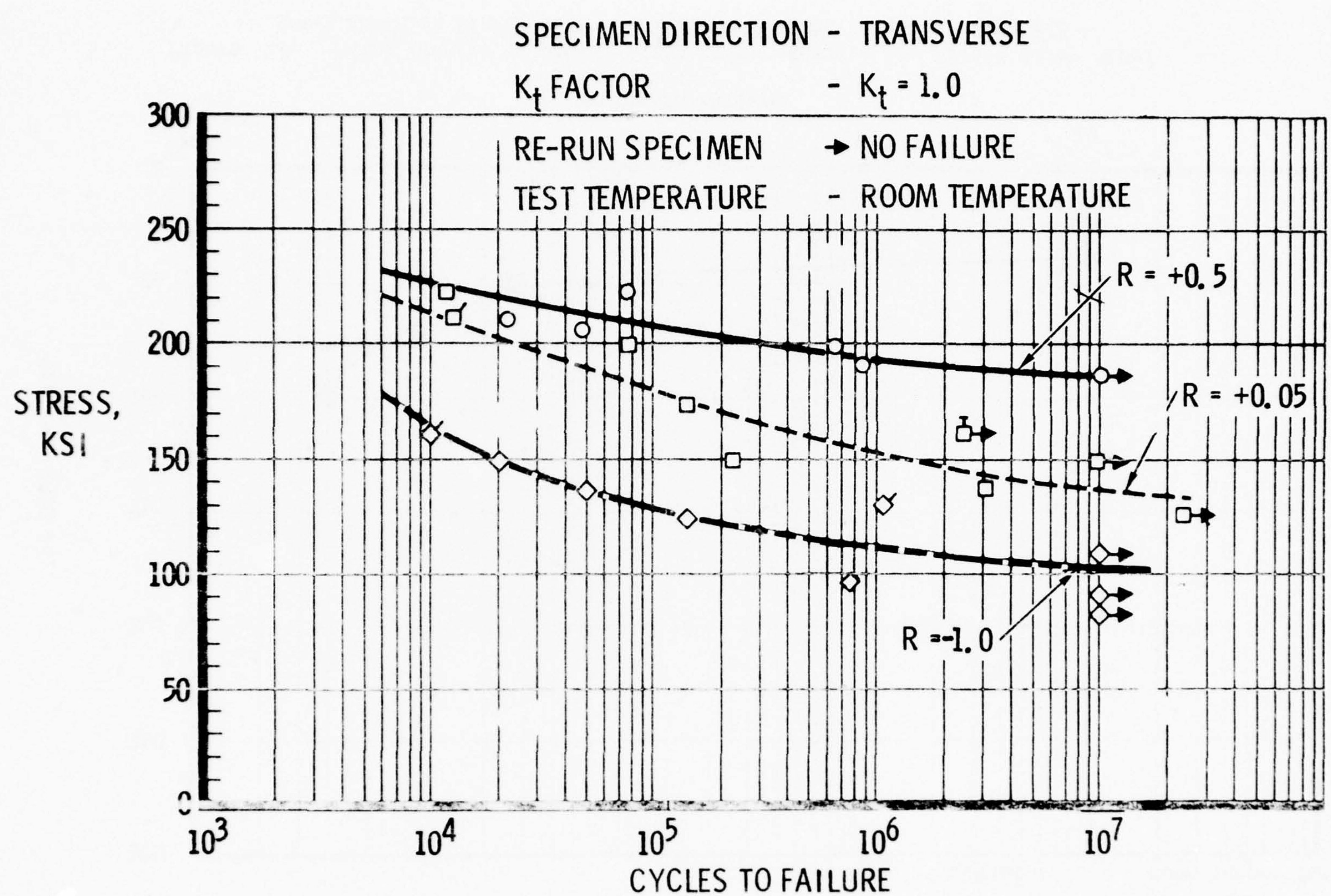


Figure 29 Effect of Stress Ratio (R) on S-N Curve

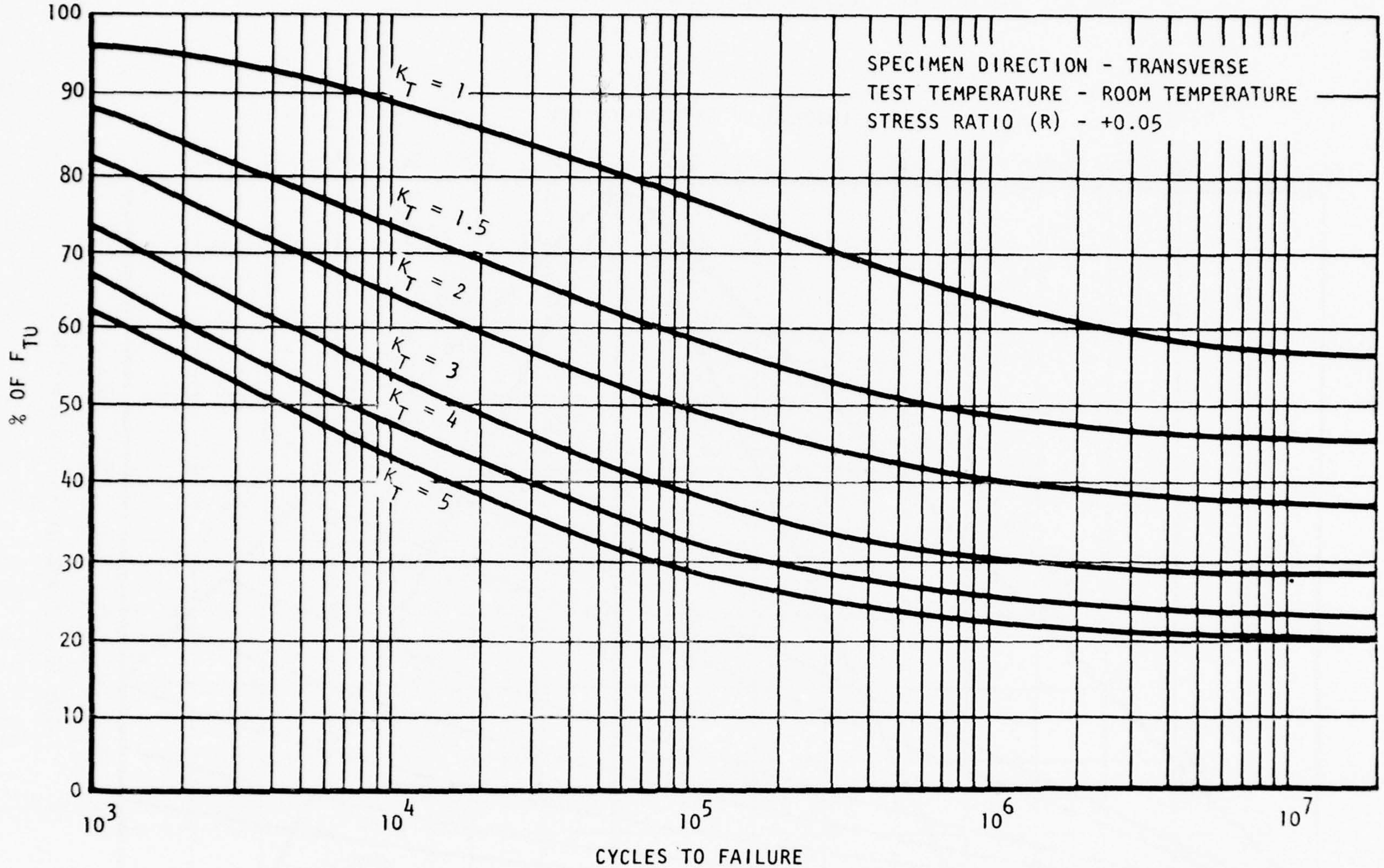


Figure 30 Effect of Stress Concentration (K_t) on S-N Curve

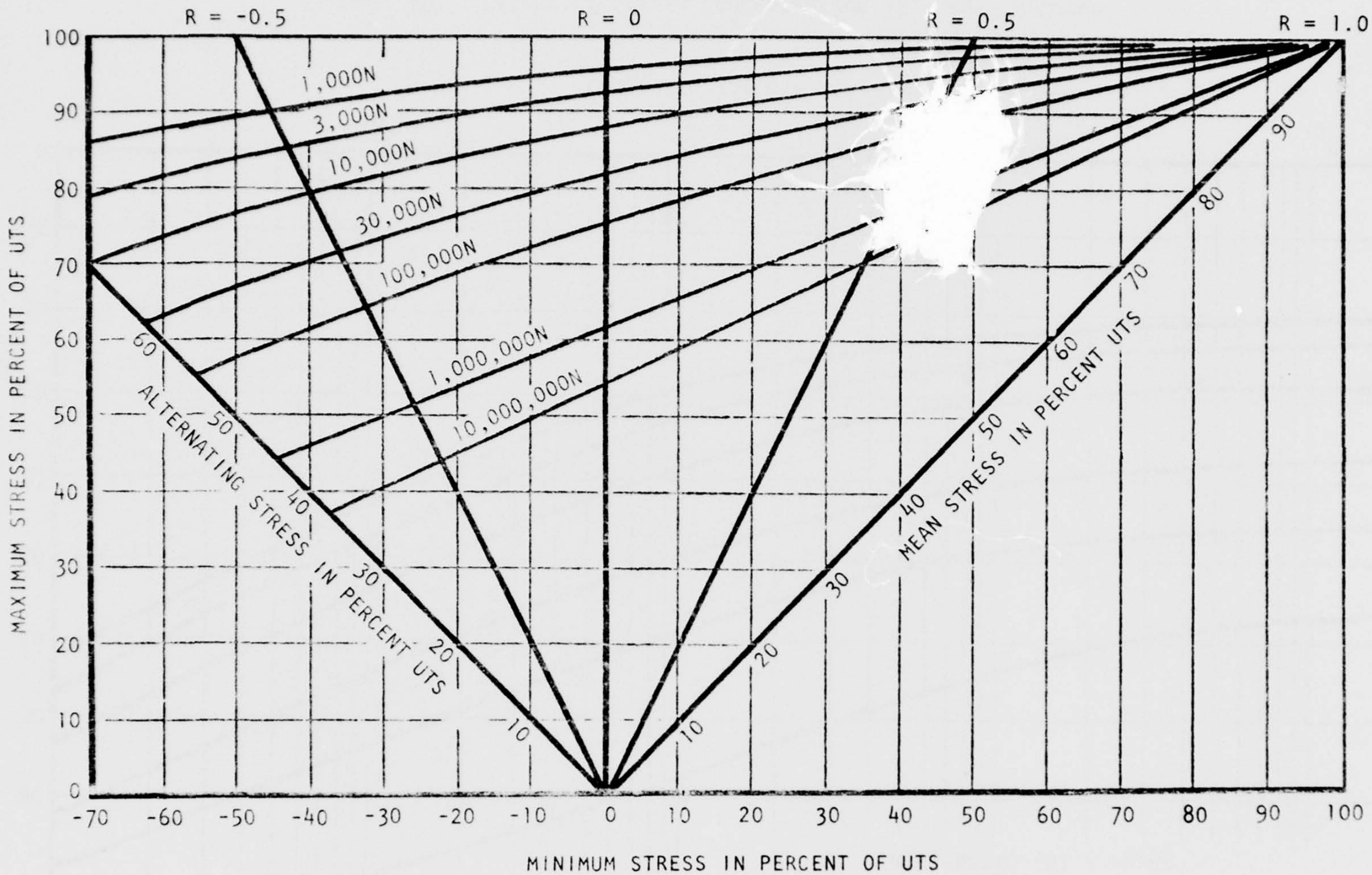


Figure 31 - Modified Goodman Diagram - Mean Data AF1410 Steel, Design F_{Tu} = 230 ksi K_T = 1 Longitudinal and Long Transverse Grain

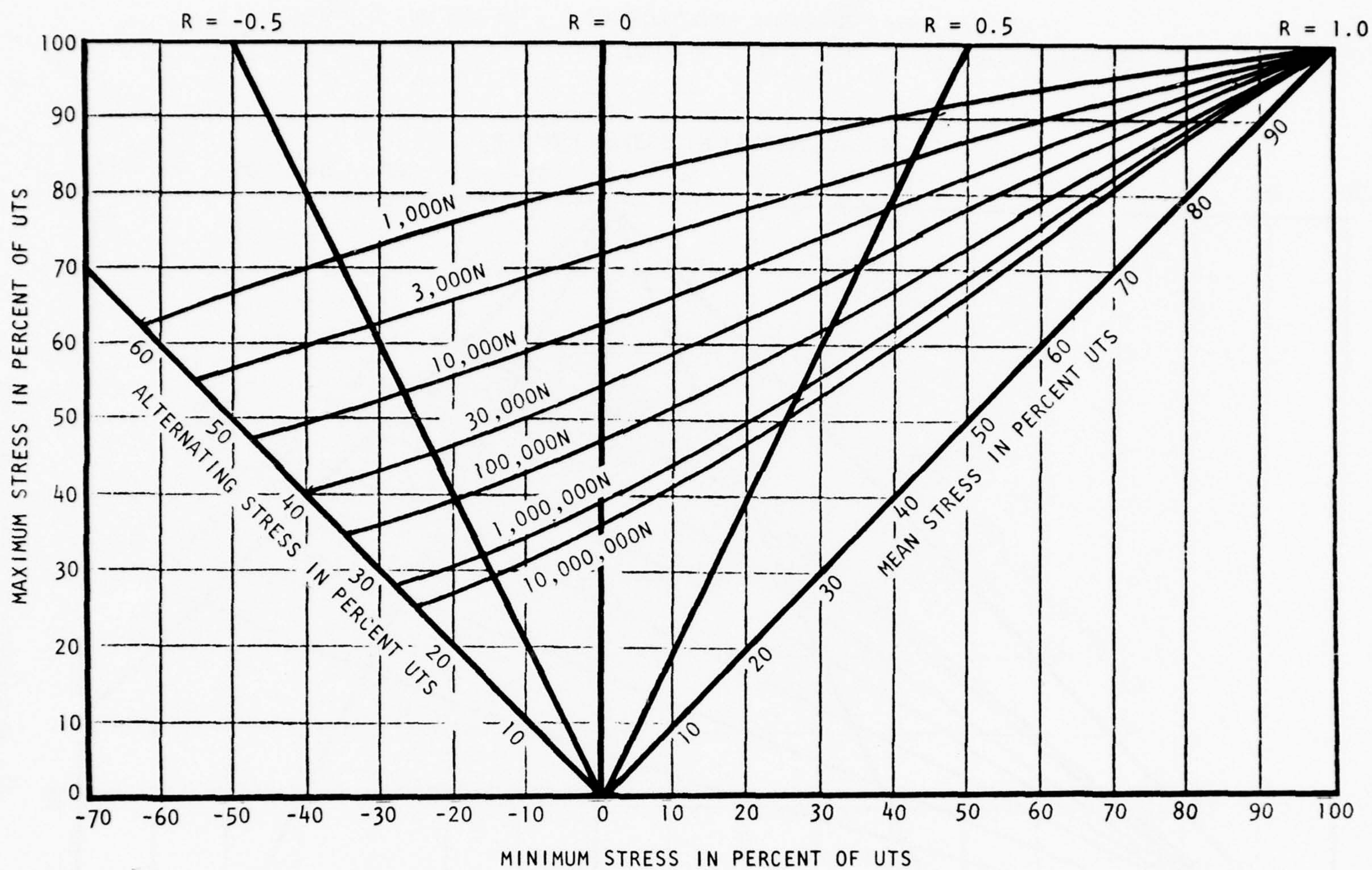


Figure 32 - Modified Goodman Diagram - Mean Data AF1410 Steel, Design F_{Tu} = 230 ksi K_T = 2 Longitudinal and Long Transverse Grain

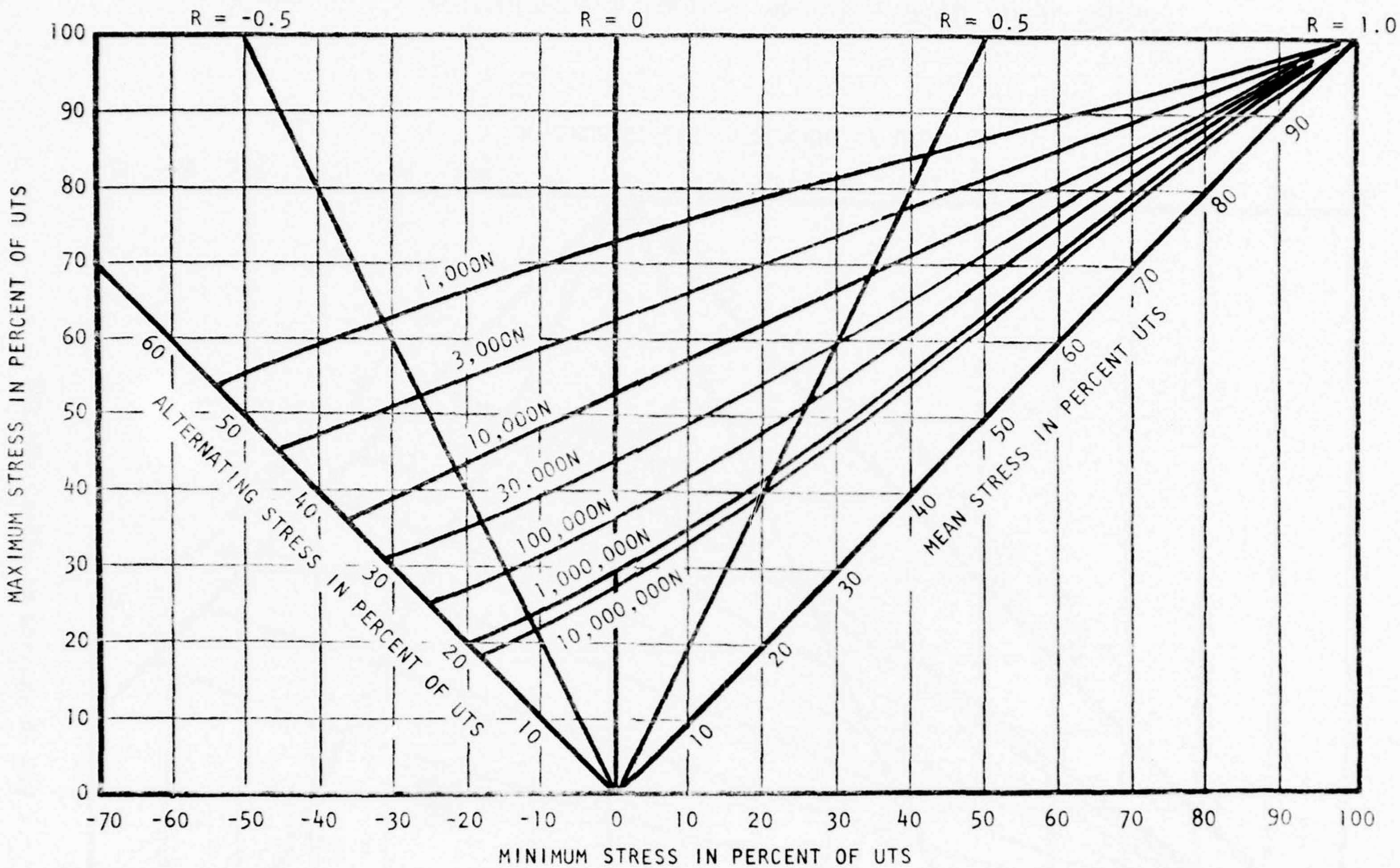


Figure 33 - Modified Goodman Diagram - Mean Data AF1410 Steel, Design F_{Tu} = 230 ksi K_T = 3 Longitudinal and Long Transverse Grain

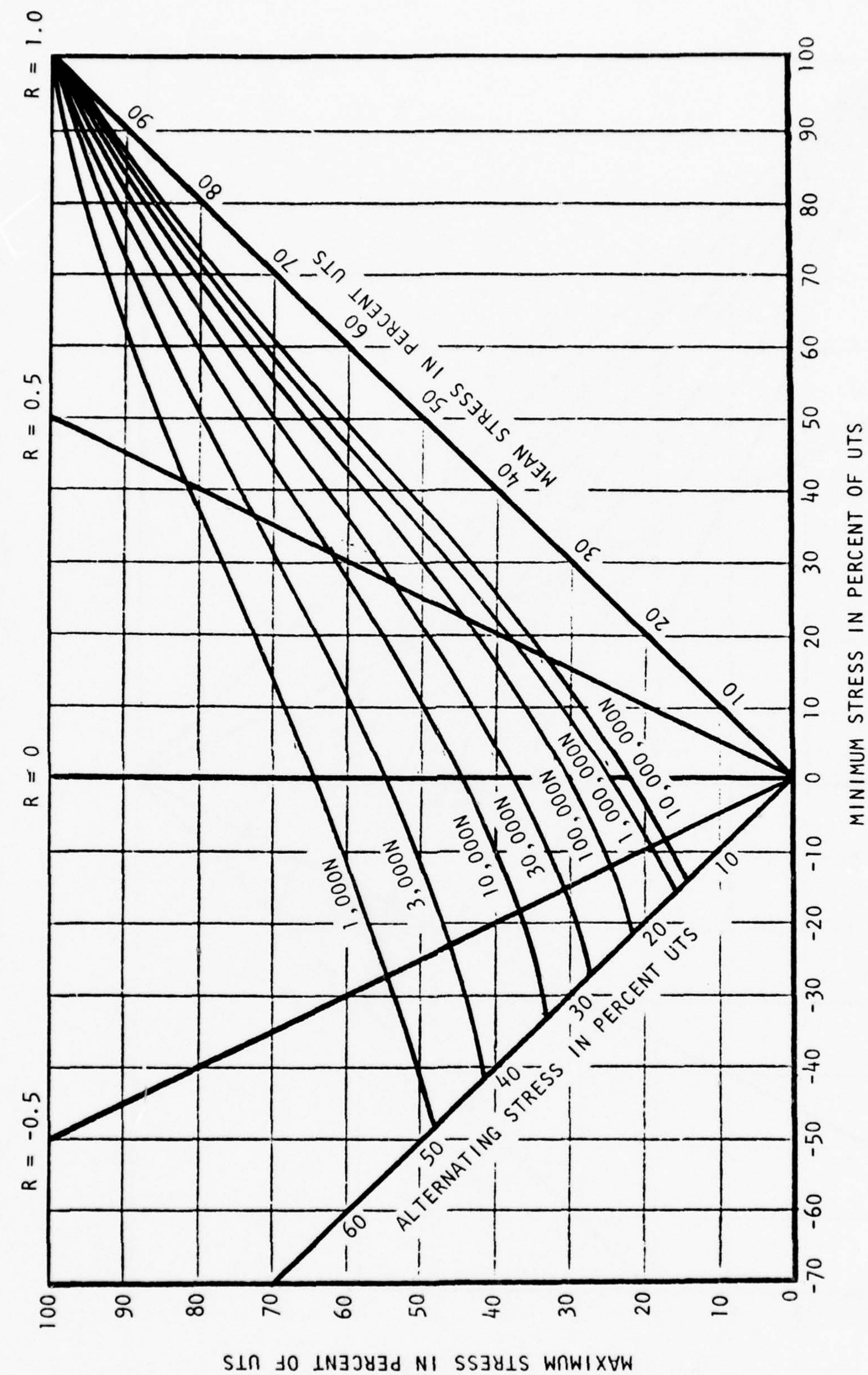


Figure 34 - Modified Goodman Diagram - Mean Data AF1410 Steel, Design F_{Tu} = 230 ksi K_T = 4 Longitudinal and Long Transverse Grain

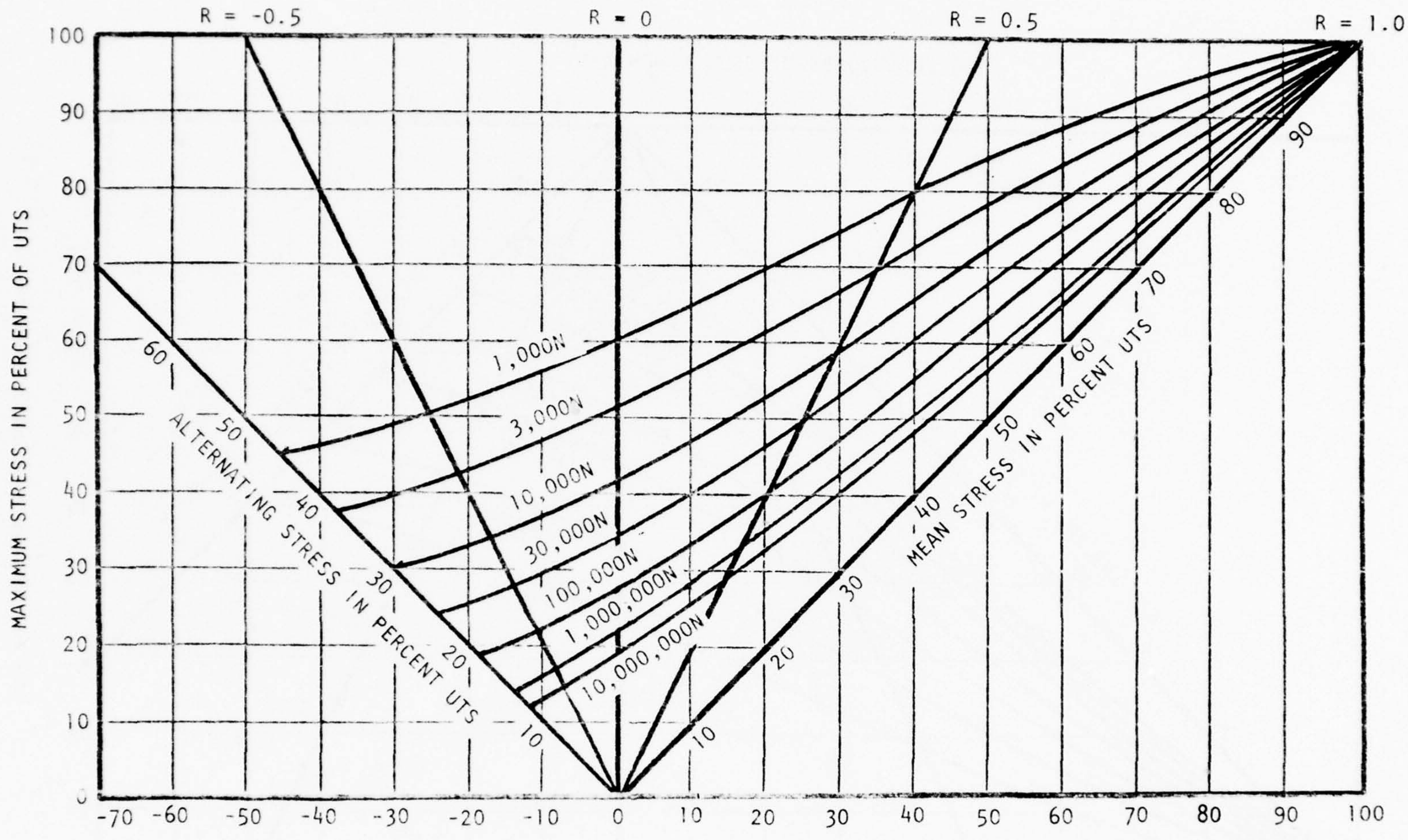


Figure 35 - Modified Goodman Diagram - Mean Data AF1410 Steel, Design F_{Tu} = 230 ksi K_T = 5 Longitudinal and Long Transverse Grain

The influence of the R-factor can be observed by comparing figure 37 (R = 0.08) with figure 39 (R = 0.3). The higher R-factor of 0.3 resulted in faster fatigue crack growth rates.

The effect of cyclic rate on crack growth rate can be observed in figure 40 . The specimen used to obtain these data was run alternately at 60 cpm and 1,800 cpm; several data points were collected at one rate and then subsequently several data points obtained at the other rate. In general, the slower rate exhibited higher crack growth rates; however, this difference becomes less as the K is increased.

The results obtained in a 3-1/2-percent NaCl solution and in simulated sump tank water are shown in figures 41 through 44. The slower, 60 cpm testing speed resulted in a slightly faster crack growth rate. This effect is probably due to the additive influence of a stress-corrosion mechanism of crack growth acting concurrently with a fatigue growth mechanism, the slower test speed resulting in longer total times at high stress-levels, and hence a greater stress-corrosion mechanism effect.

One specimen was tested at -65° F, and the data obtained are shown in figure 45.

A typical da/dN specimen resulting from these series of tests is shown in figure 46 . Note that the starter-crack front (shown on the left side of the top photo) exhibited very little waviness, as compared to the K_{Ic} specimen (see figure16). The crack plane remained very close to the desired path of growth (90° to the applied stress) up to the point of unstable crack growth.

Stress Corrosion ($K_{I_{scc}}$)

Results of stress-corrosion tests are shown in table 21 for sump tank water and table 32 for 3-1/2-percent NaCl. Initially, it was intended to calculate the K_{Iscc} value from each of several specimens after the crack extension had ceased. However, two occurrences made this approach to K_{Iscc} determination inappropriate. First, some of the specimens, those loaded to a higher initial stress intensity, exhibited crack branching as shown in figure 47 . Secondly, the stress corrosion crack front was very erratic, making any calculation of stress intensity after crack arrest questionable. The fracture faces of two typical specimens are shown in figure 48 . In view of these experimental difficulties, it was decided to test additional specimens at various initial stress intensities in an effort to determine that stress intensity below which no cracking occurred (much the same as one would do in constructing a fatigue S/N curve). Additionally, the crack length recorded was the longest crack measurable on the face of the specimen. The length recorded was the actual crack length which occurred during exposure to the environment (see figure 49).

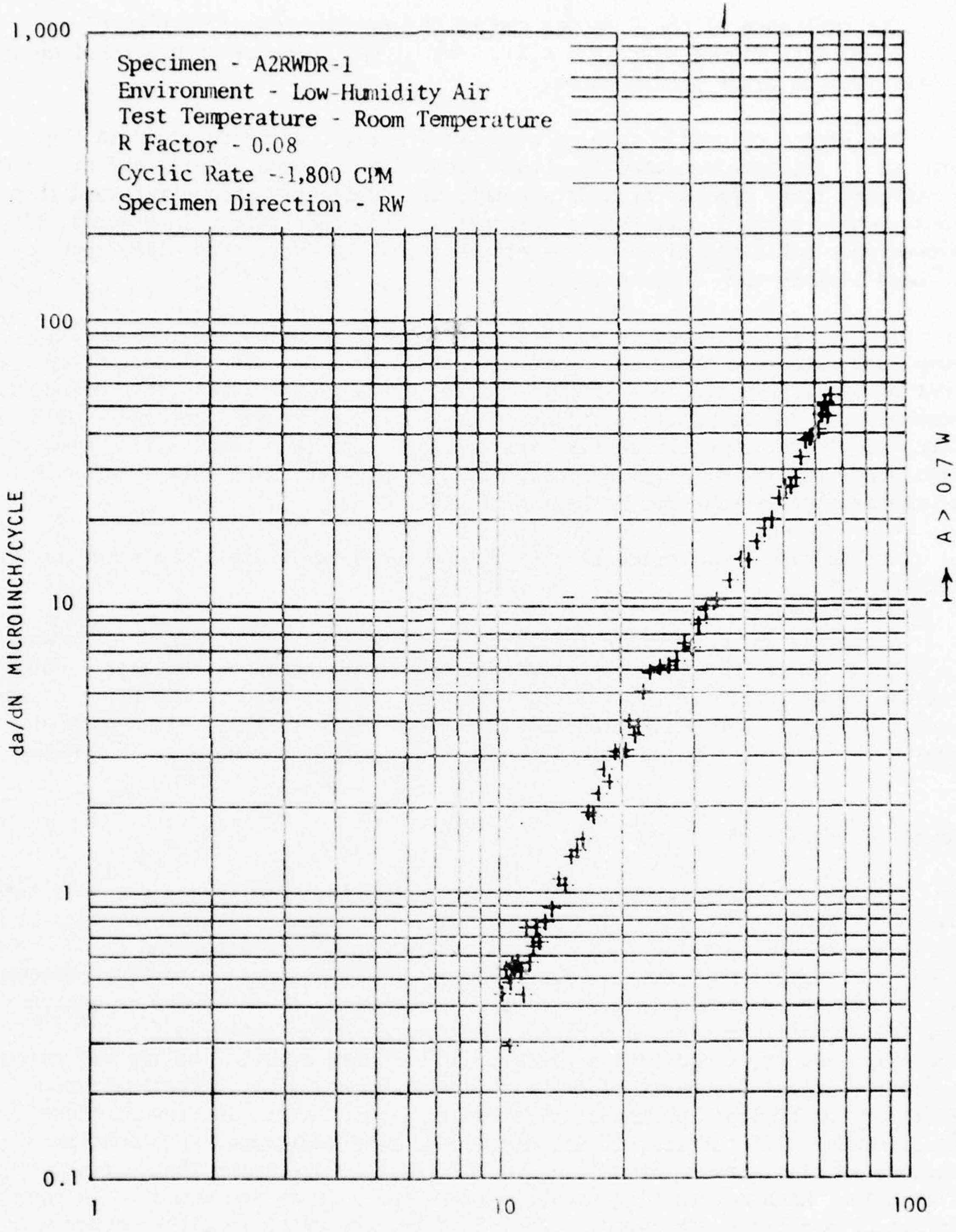


Figure 36 Parent Metal da/dN, Air

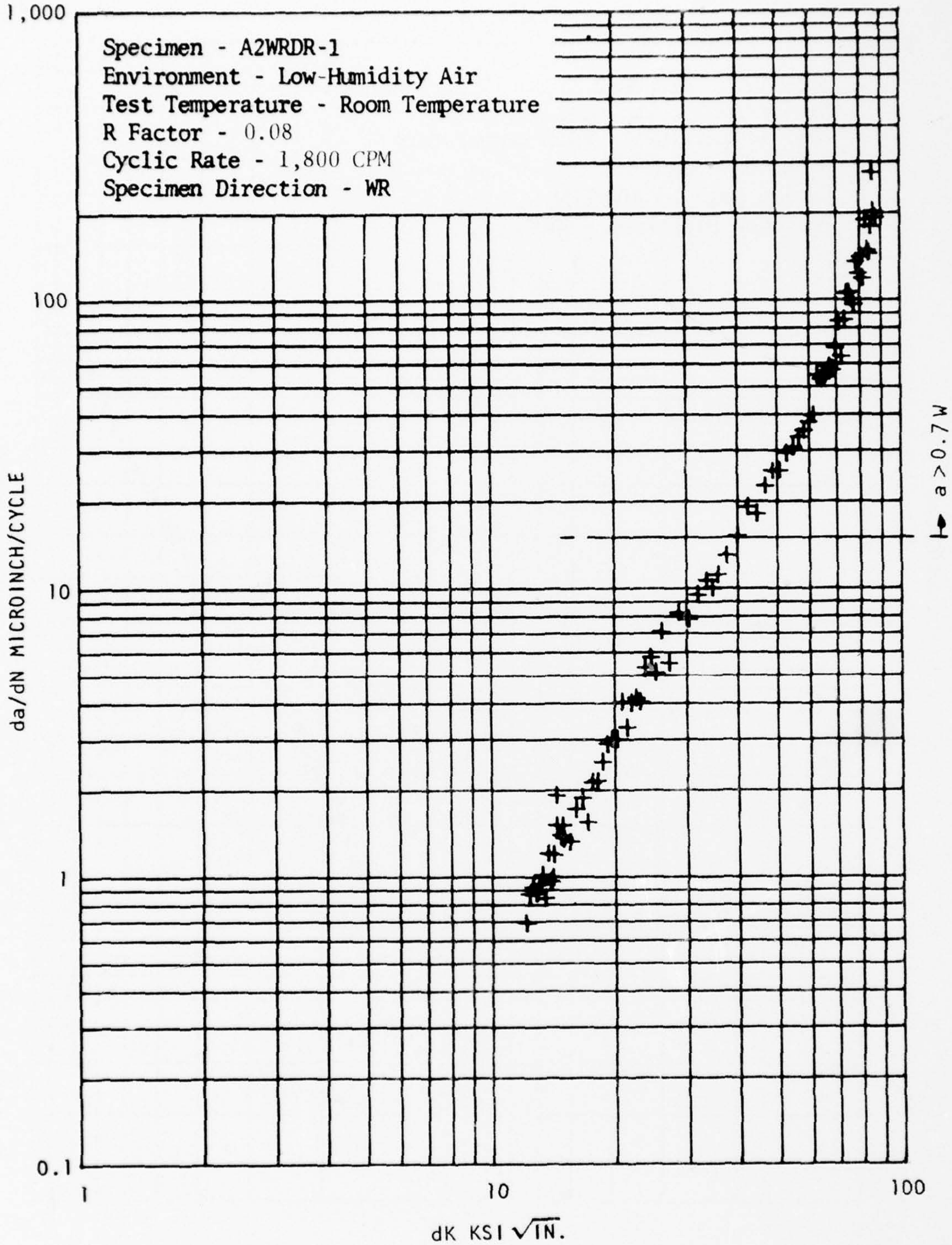


Figure 37 Parent Metal da/dN, Air

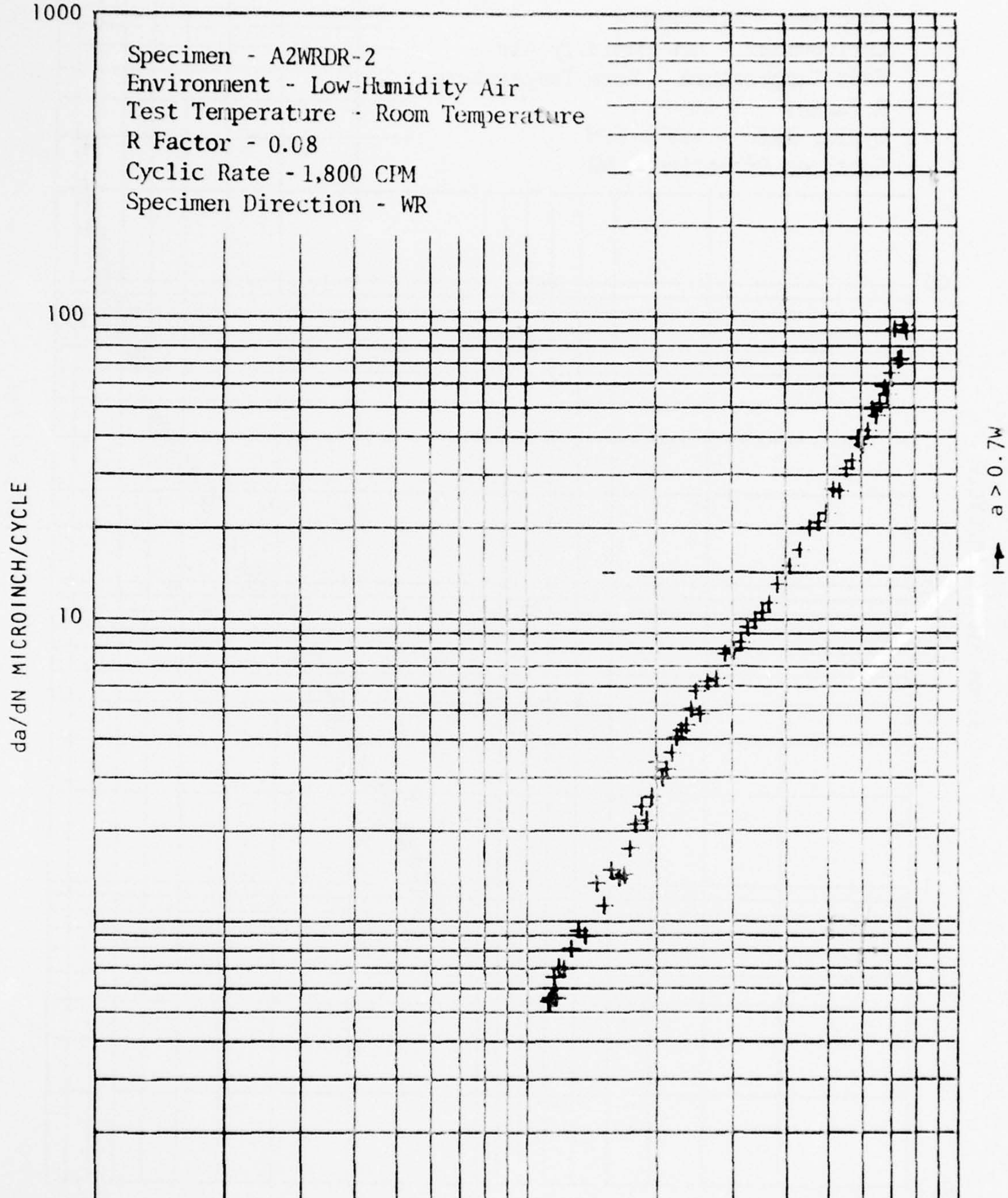


Figure 38 Parent Metal da/dN, Air

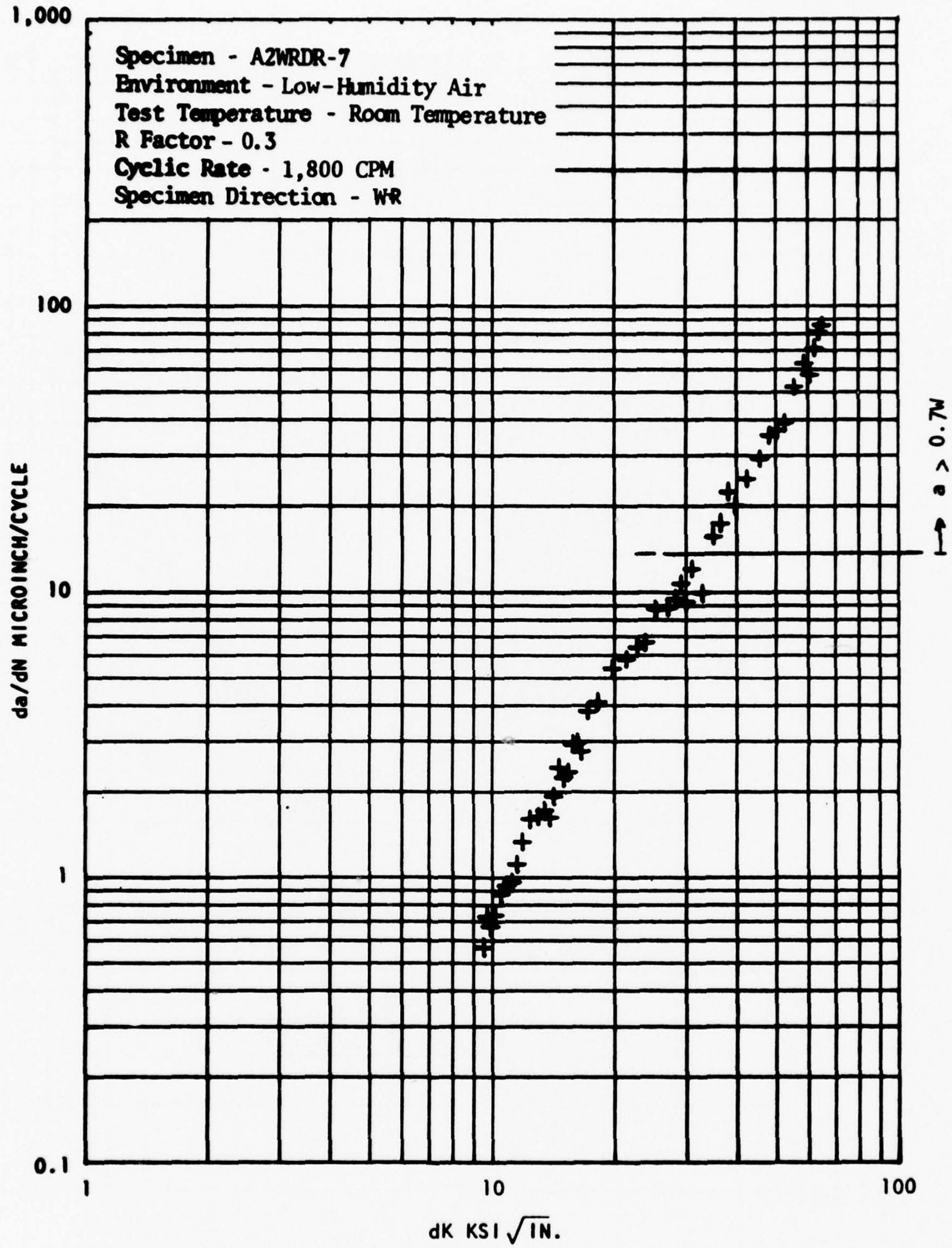


Figure 39   Parent Metal da/dN, Air

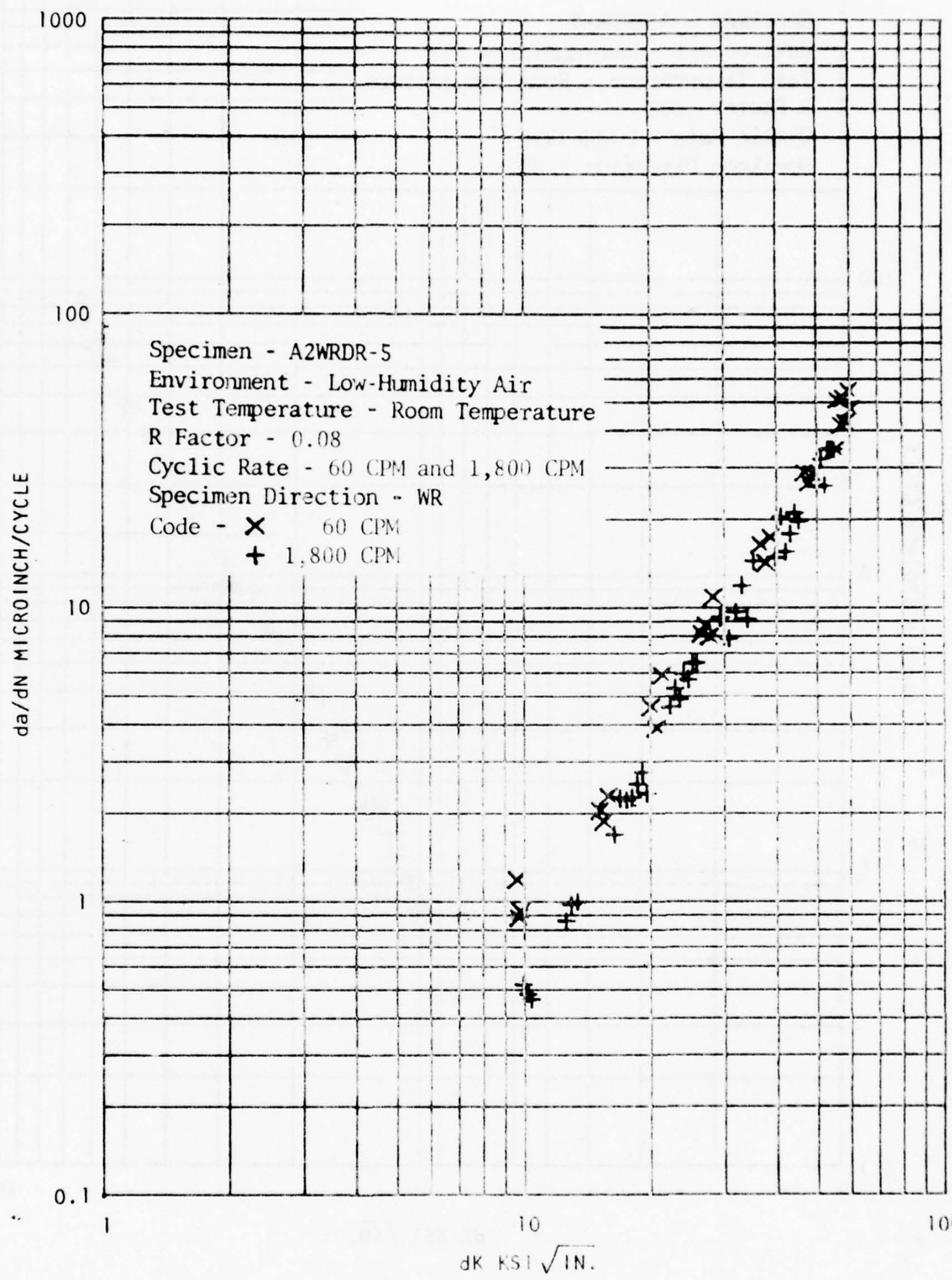


Figure 40 Parent Metal da/dN, Air

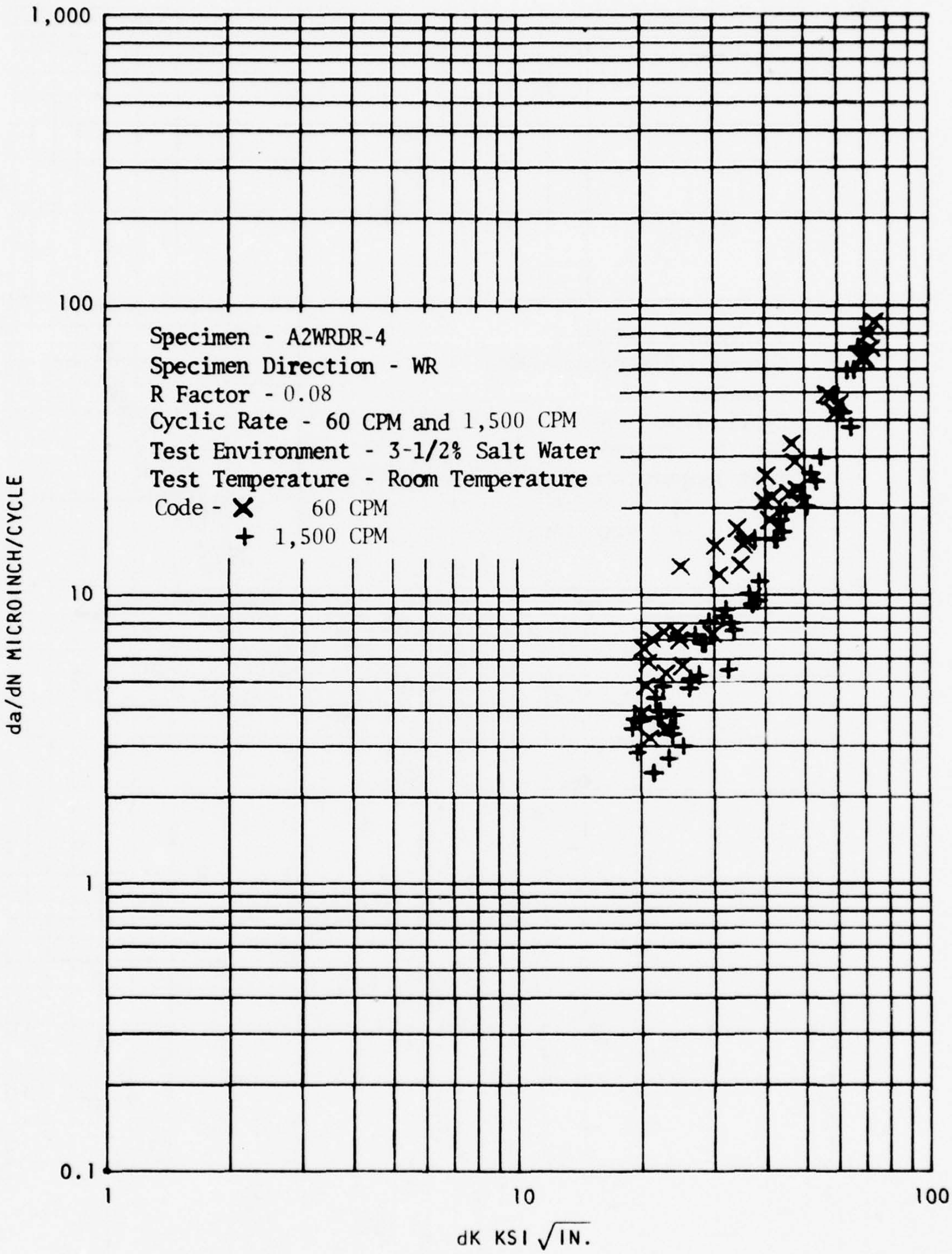


Figure 41 Parent Metal da/dN, 3 1/2-Percent NaCl

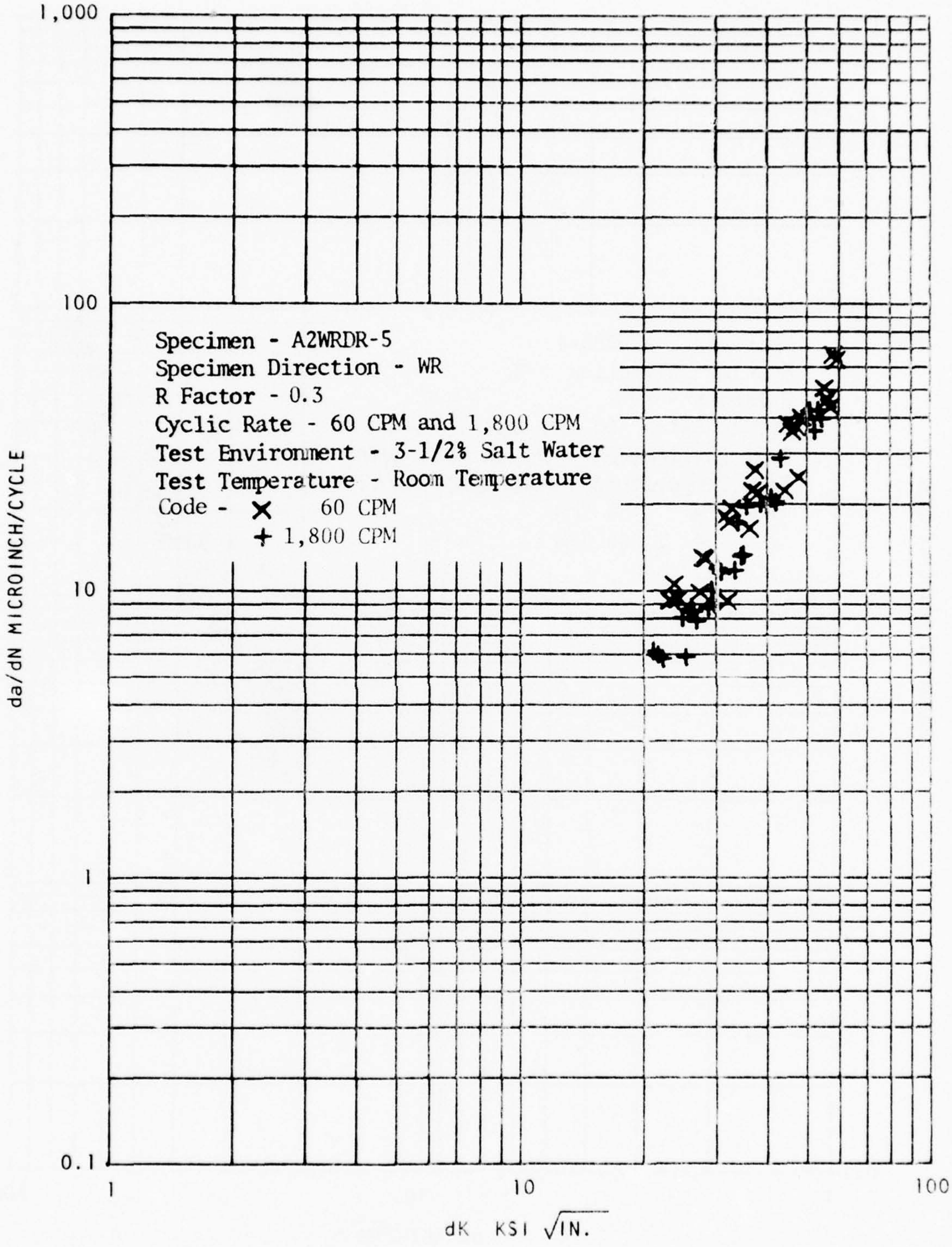


Figure 42 Parent Metal da/dN, 3 1/2-Percent NaCl

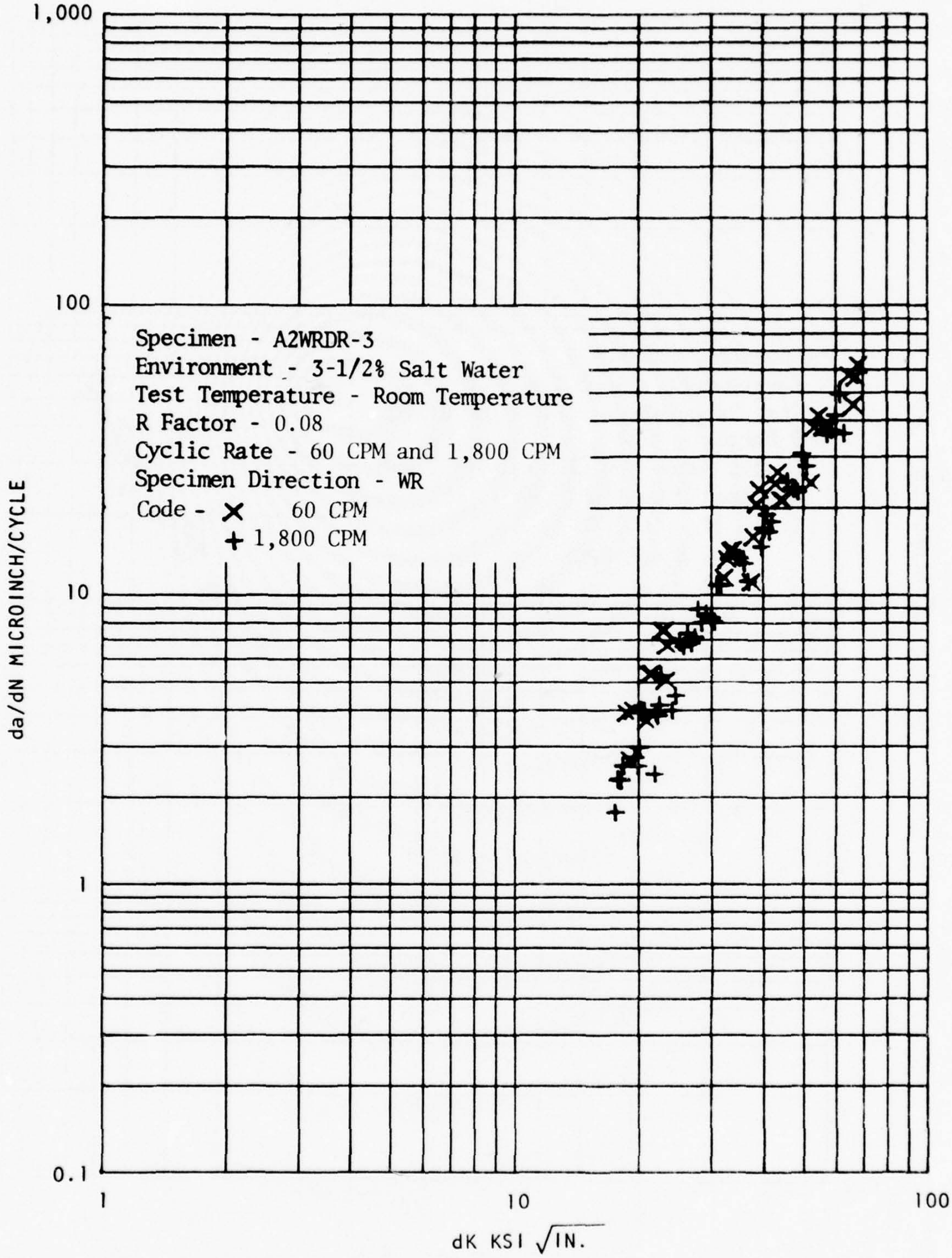


Figure 43 Parent Metal da/dN, 3 1/2-Percent NaCl

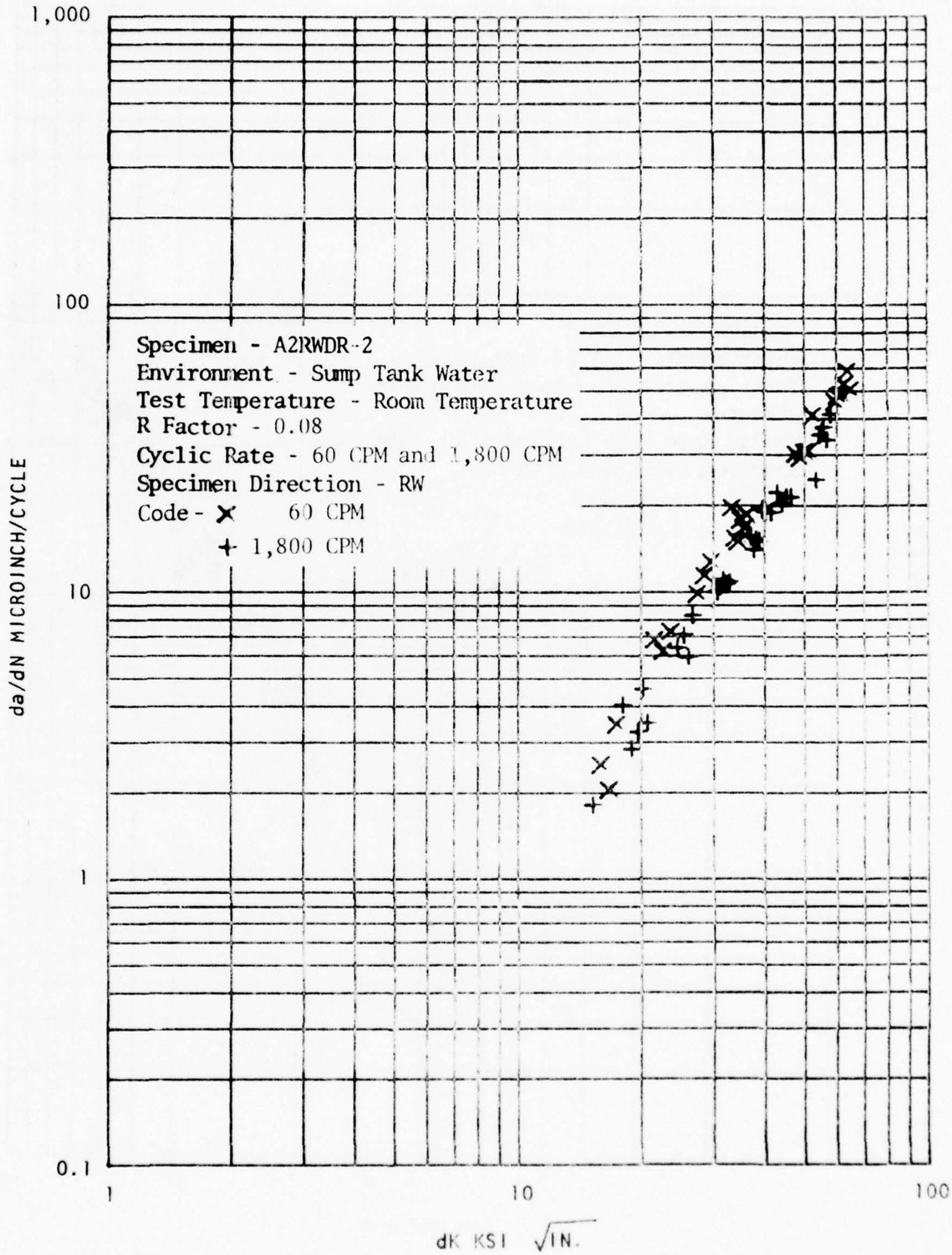


Figure 44 Parent Metal da/dN, Sump Tank Water

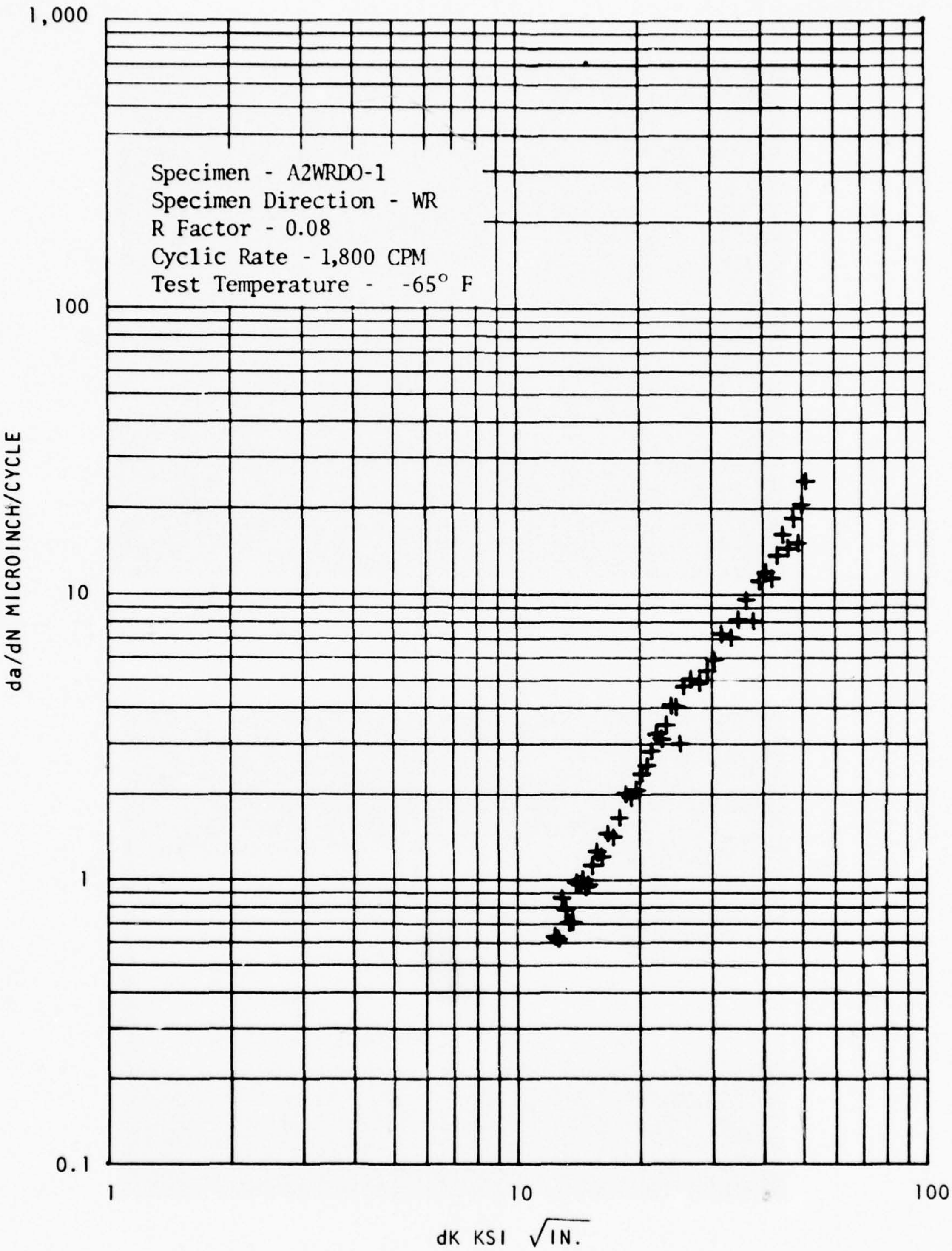
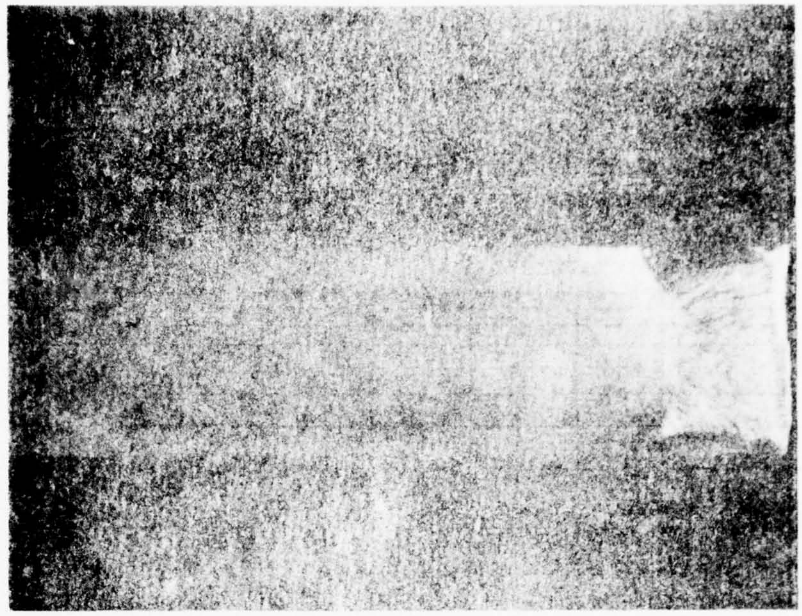


Figure 45 Parent Metal da/dN, -65° F



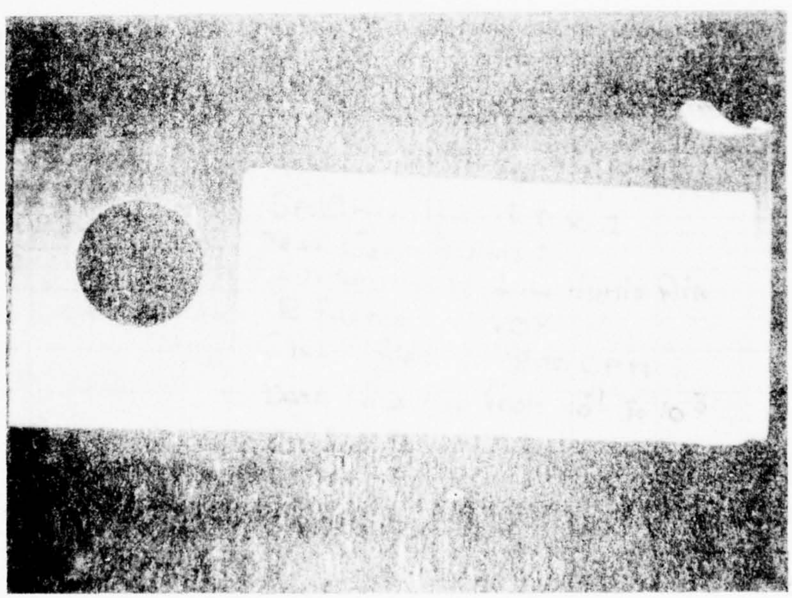


Figure 46. Typical da/dN Specimen

Table 21

CRACK GROWTH OF STRESS-CORROSION SPECIMENS
TESTED IN SUMP TANK WATER

Specimen No.	Orientation	K_{Ii} ksi$\sqrt{in.}$	Crack Growth Measured*		
			100 hr	500 hr	1,000 hr
K	RW	60	0.00	0.00	0.00
H		40	0.17	0.26	0.27
J		40	0.05	0.19	0.21
L		30	0.13	0.16	0.17
A**	WR	120	0.51	0.63	0.63
B**		100	0.31	0.60	0.70
E**		80	0.36	0.53	0.55
F		60	0.00	0.00	0.00
B		50	0.18	0.24	0.25
D		40	0.00	0.00	0.00
G		30	0.11	0.16	0.17

NOTES:

*Length of longest crack at surface

**Crack-branched

Table 22

CRACK GROWTH OF STRESS-CORROSION SPECIMENS
TESTED IN 3-1/2-PERCENT NaCl

Specimen No.	Orientation	K_{Ii} ksi$\sqrt{in.}$	Crack Growth		
			50 hr	100 hr	500 hr
M*	RW	70	0.140	0.160	0.240
T		40	0.065	0.080	0.155
W		40	0.150	0.205	0.275
V		35	0.080	0.100	0.130
U		30	0.055	0.070	0.115

*Crack-branched

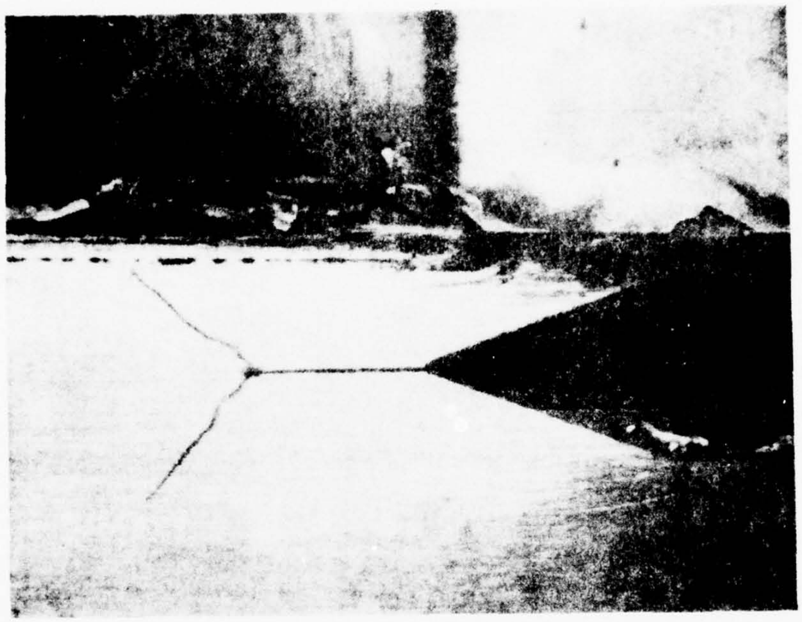


Figure 47 Branched Stress Corrosion Crack

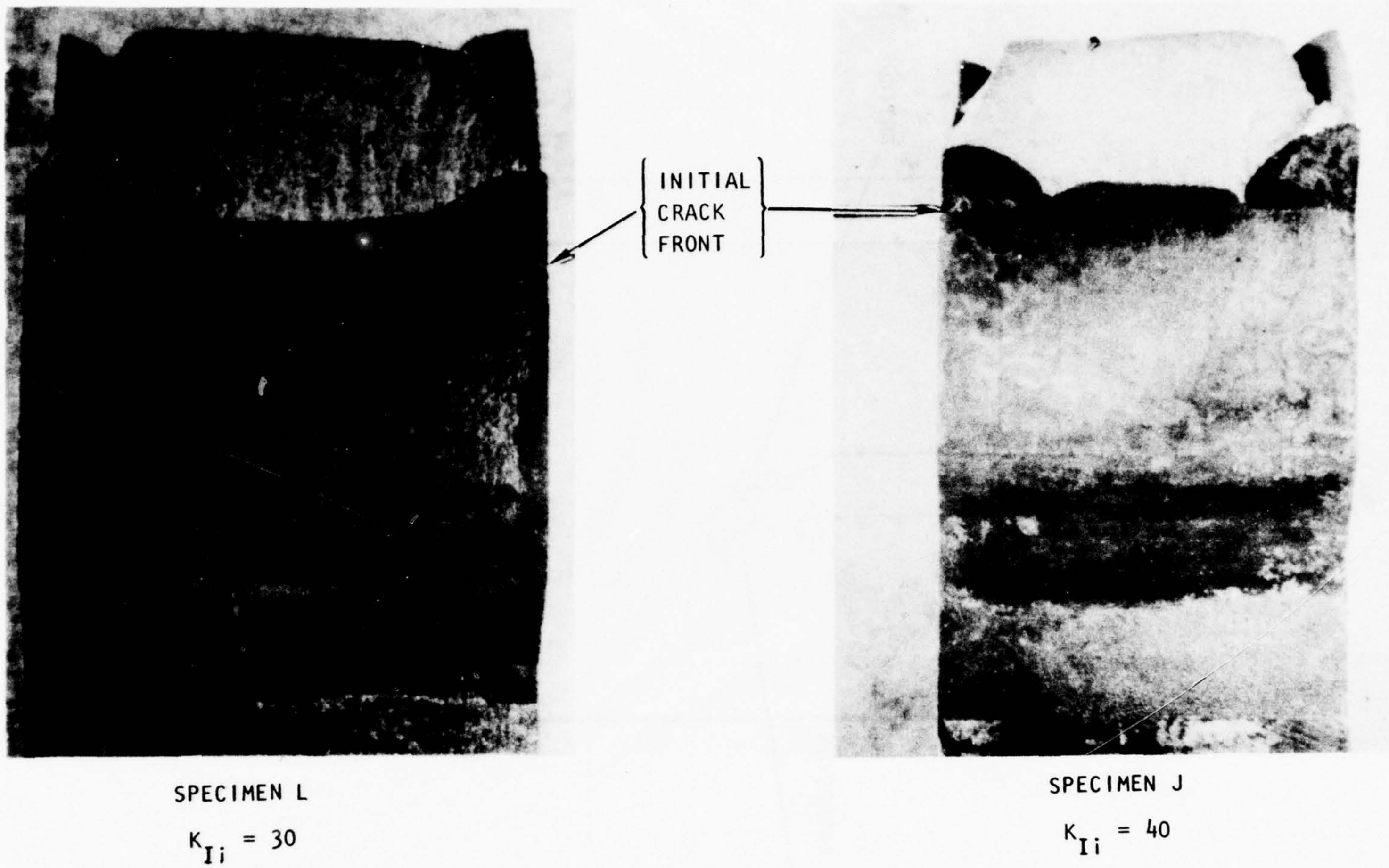


Figure 48 Fracture Faces of Typical Stress-Corrosion Specimens

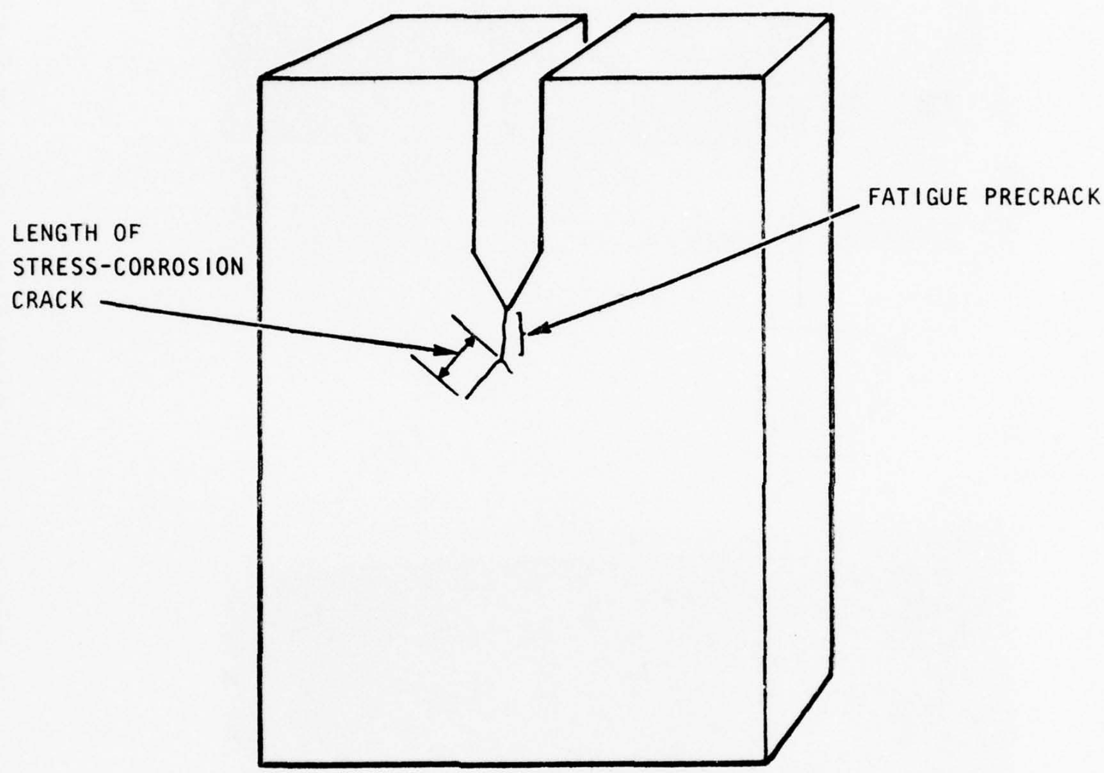


Figure 49 Crack Length Measurement in Stress-Corrosion Specimens

In reviewing the data obtained in the sump tank water, table 21, it is apparent that no specific value can be assigned to K_{Iscc} for these specimens. In the RW direction, no growth occurred at K_{Ii} of 60, but specimens tested at lower values, even down to 30, showed some growth. Similar results were exhibited by the specimens with a WR orientation. It would appear, however, that one should expect little or no stress-corrosion cracking at stress intensities of 60 Ksi $\sqrt{\text{in.}}$ or lower.

The results of the stress-corrosion tests in 3-1/2-percent NaCl solution are presented in table 22. Unlike the results obtained in simulated sump tank water, significant crack growth occurred at stress intensities as low as 30 ksi $\sqrt{\text{in.}}$ Again, crack branching occurred at the higher initial stress intensity. Recognizing the scatter which is inherent in stress-corrosion test results, the K_{Iscc} in 3-1/2-percent NaCl was judged to be approximately 30 ksi $\sqrt{\text{in.}}$

Manufacturing Process Effects

The results of the tests on low-stress grinding, with and without shot peening, are shown in the S/N curve of figure 50. Half of the specimens failed in the threads rather than the test section; these are indicated by a small "t" on top of the symbol. Three each of the ground only and ground plus shot peen specimens did fail in the test section, and when these are compared to the S/N curve for machined specimens (the dashed curve in figure 48), it is apparent that (1) no deleterious effect on fatigue occurred as a result of the grinding, and (2) shot peening did not enhance the fatigue life of the ground surface.

The effects of Chromium, Ti-Cad, and Electroless Nickel plating on the fatigue life is shown in the S/N curve of figure 51. Chromium and Electroless Nickel plating both lowered the fatigue life significantly, much the same as occurs on high-strength, low-alloy steels. Shot peening prior to plating, as is the practice on other high-strength steels, would be a desirable choice for AF 1410 that is to be Chromium or Electroless Nickel-plated. Ti-Cad plating on the other hand showed no fatigue degradation, and shot peening would appear unnecessary for Ti-Cad-plated AF 1410 parts.

The results of the sustained-load, notched tensile tests to characterize the susceptibility of AF 1410 to hydrogen embrittlement are shown in figure 52 The upper portion represents specimens which were not baked, and the lower portion the results on the baked specimens. No susceptibility to the hydrogen enduced during chromium plating is suggested by these data. Apparently, the hydrogen which entered the steel during plating diffused out prior to loading of the specimen; at least enough appears to have diffused out of the steel such that the amount remaining was insufficient to produce any significant delayed failures. It would appear from this cursory evaluation of

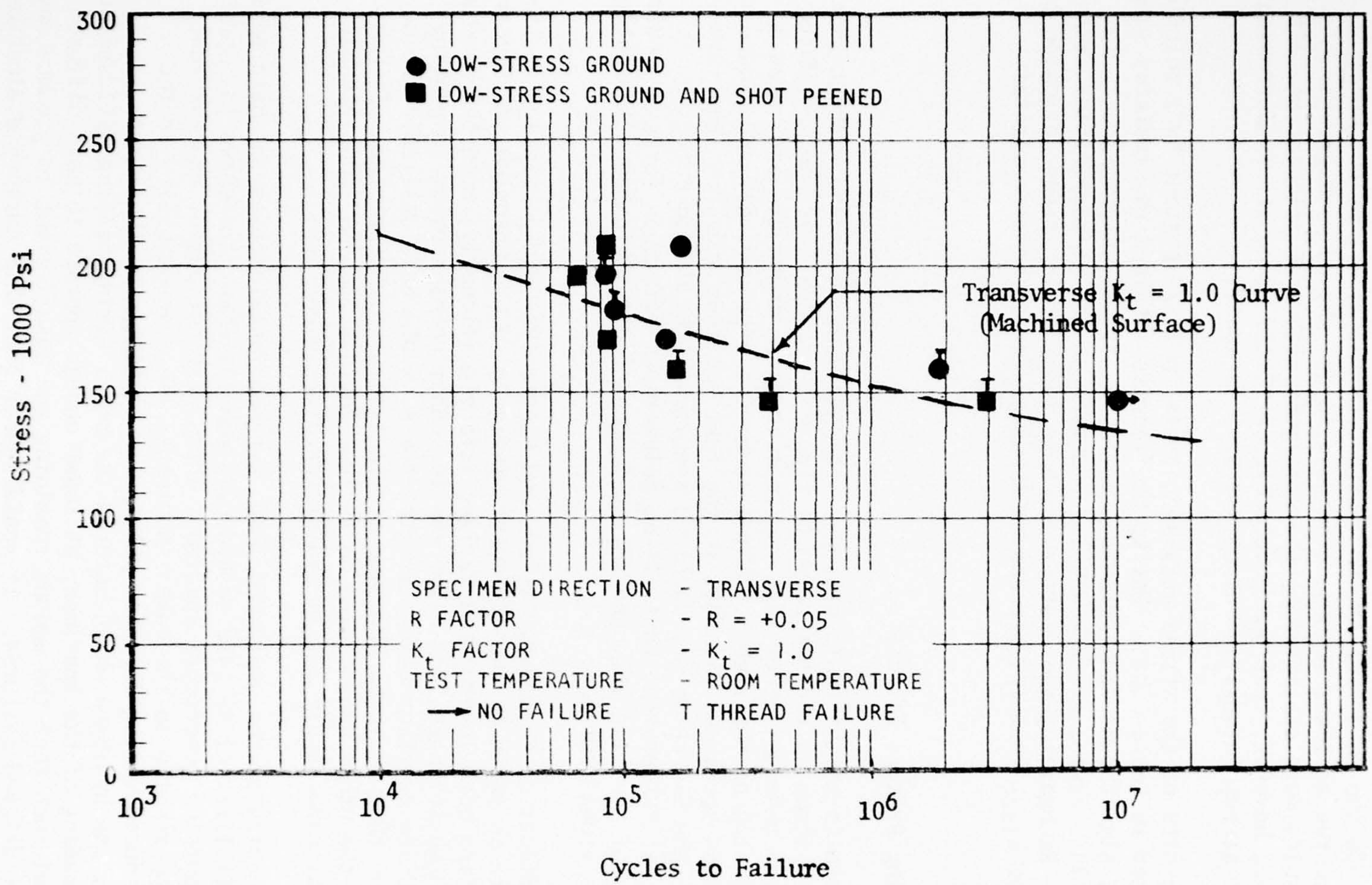


Figure 50 Axial Tension - Tension Fatigue Test Results For Low-Stress Ground And Low-Stress Ground Plus Shot Peened AF1410 Alloy Steel

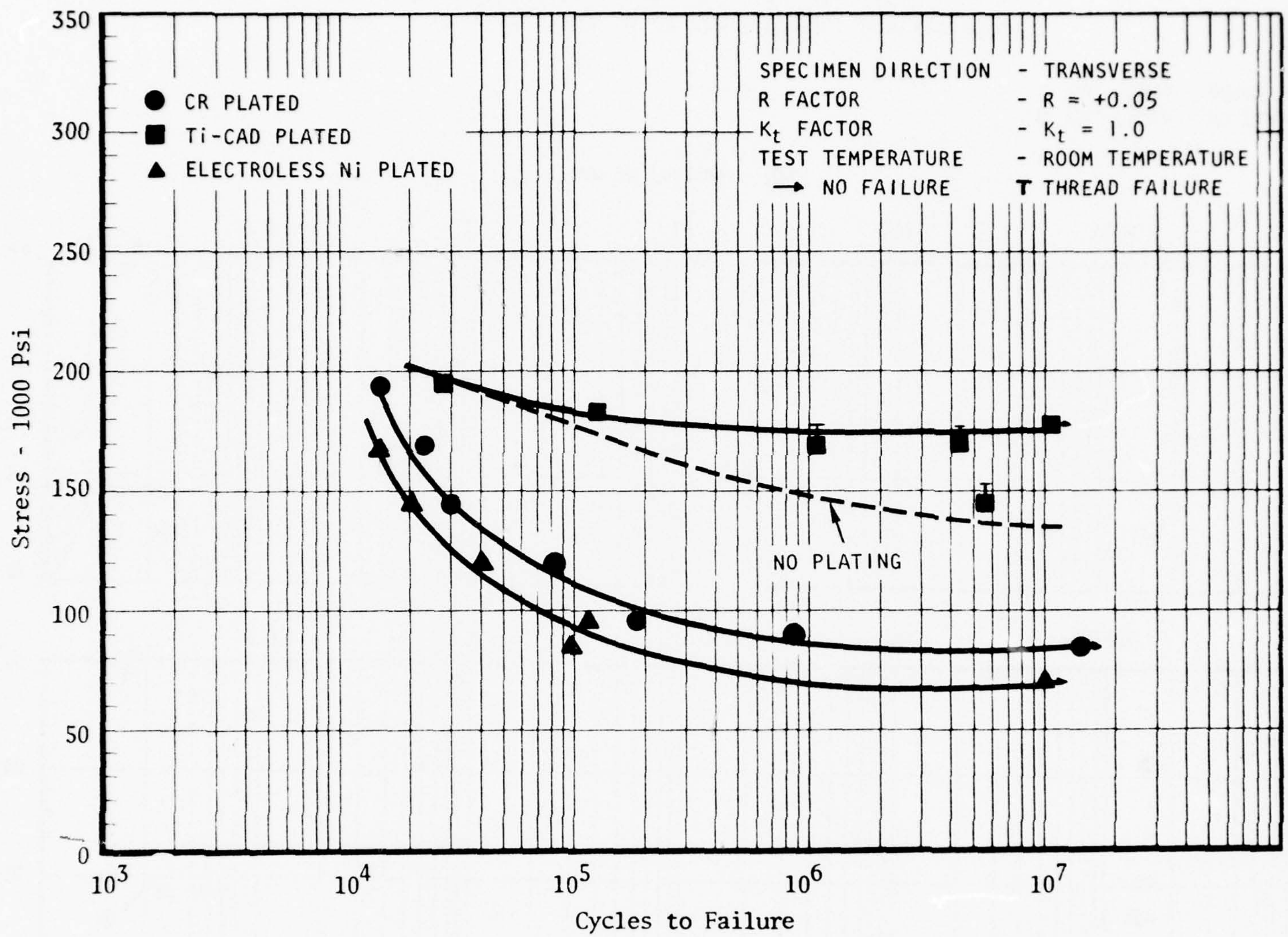


Figure 51 Axial Tension - Tension Fatigue Test Results For Plated AF1410 Alloy Steel

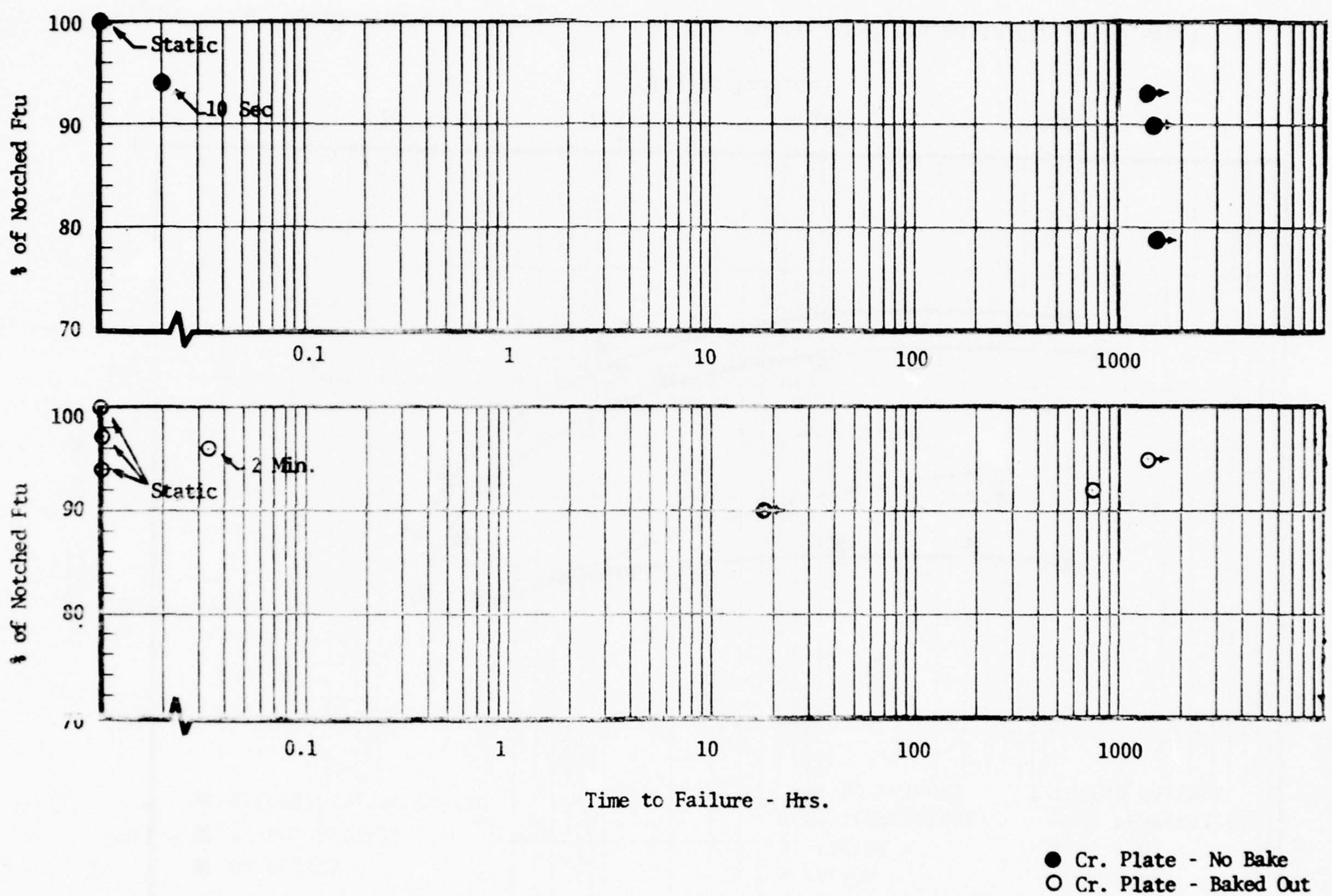


Figure 52 Characterization of the Hydrogen Embrittlement Susceptibility of the Alloy Steel AF1410

hydrogen-embrittlement susceptibility that AF 1410 is less susceptible to this phenomenon than low-alloy steels at this yield strength level.

Preliminary Design Allowables

Obviously, the limited amount of mechanical property data generated in this program were not adequate to develop regular MIL-HDBK-5 values, which require a rather substantial data base. However, sufficient data were planned and generated to compute derived values (ratios) which provided for the development of "S" type design allowables. The "reduced ratio" procedure described in MIL-HDBK-5 was used in establishing Fcy, F_{su}, F_{bru}, and F_{bry} allowables. The reduced ratios used, together with the preliminary design allowables, are shown in table 23.

Table 23

PRELIMINARY DESIGN ALLOWABLES
(ROOM TEMPERATURE)

Property	Allowable, ksi
F_{tu}	235
F_{ty}, 0.2% offset	220
F_{cy}	231
F_{su}	139
F_{bru} (e/D = 2.0)	438
F_{bry} (e/D = 2.0)	324
E x 10^3	28.0
Property	**Reduced Ratio**
F_{cy}	1.0489
F_{su}	0.59169
F_{bru} (e/D = 2.0)	1.86401
F_{bry} (e/D = 2.0)	1.4716

Weld Properties

Tensile

Results of the tensile tests at room temperature on butt welds, with bead on and bead off, are shown in table 24 . Slightly higher properties were achieved with the bead-on specimens. The effect of single and multiple repairs on tensile properties is also shown in table 24 , and indicate no degradation of properties occurs with a single repair. However, multiple repairs tend to lower the yield strength. Since only an aging treatment was performed after the welding, the lowering of yield strength with multiple repairs is probably the result of overaging occurring during the second repair. Both single and multiple repair welding had a deleterious effect on elongation.

Butt welds tested at -65° F resulted in the properties shown in table 25 . The tensile strength was unaffected by repairs or whether tested with the bead on or the bead off. The elongation reported for the three bead-on specimens which failed in the parent metal, specimen No. T-32, T-31, and T-32 is higher than the true elongation since the specimen halves could not be fitted together tightly to measure the elongation; an air-gap existed which is included in the number calculated by this method. The rectangular specimen cross section yielded more at the four corners than the center portion, making it impossible to fit the two halves together tightly.

The results obtained for the partial penetration fillet welds are shown in table 26 for 0.200-inch thick leg and table 27 for the 0.375-inch thick leg specimens. The two specimens in table 26 exhibiting the lower than average values, No. WT-1 and WT-2, had root cracks. No such cracks appeared in the fillet welds tested with the 0.375-inch leg specimen, and all five of these specimens exhibited uniformly high values.

The tensile result for the full-penetration fillet welds are tabulated in table 28 for the symmetrical weld and in table 29 for the asymmetrical weld. Failure of both types of welds occurred in the HAZ of the load-carrying leg, and no significant differences in tensile strength between the two types of welds are apparent.

CHARPY

The charpy impact test results are tabulated in table 30 . The average value for the weld deposit was higher than that obtained for the heat-affected zone. Considerable scatter exists within both groups of data.

Table 24

ROOM TEMPERATURE TENSILE PROPERTIES FOR BUTT-WELDED AF1410 ALLOY STEEL

Specimen Ident	Specimen Condition	F_{tu} ksi	F_{ty} ksi	Percent Elong 2 in.	Failure Location
T-5	Weld bead left on	245.4	225.5	10.0	Weld metal
T-26	Weld bead left on	251.5	237.2	10.0	Weld metal
T-27	Weld bead left on	257.2	230.5	20.0	Parent metal
T-28	Weld bead left on	247.3	228.2	10.0	Weld metal
Avg		250.4	230.4	12.5	
T-1	Weld bead ground off	230.1	219.3	13.5	Weld metal
T-2	Weld bead ground off	228.8	217.5	9.5	Weld metal
T-3	Weld bead ground off	230.3	222.2	14.5	Weld metal
T-4	Weld bead ground off	239.7	221.8	10	Weld metal
Avg		232.2	220.2	12	Weld metal
T-9	Single repair bead off	225.2	239.5	10	Weld metal
T-10	Single repair bead off	236.7	213.5	8	Weld metal
T-11	Single repair bead off	238.6	212.0	8	Weld metal
T-12	Single repair bead off	236.2	209.1	10	Weld metal
Avg		235.9	219.2	9.0	Weld metal
T-17	Multiple repair bead off	240.6	207.2	11	Weld metal
T-18	Multiple repair bead off	236.8	201.3	7	Weld metal
T-19	Multiple repair bead off	240.5	204.9	8	Weld metal
Avg		239.3	204.5	9.0	

Table 25

CRYOGENIC (-65° F) TENSILE PROPERTIES FOR
BUTT-WELDED AF1410 ALLOY STEEL

Specimen Ident	Specimen Condition	F_{tu} ksi	Percent Elong 2 in.	Failure Location
T-29	Weld bead left on	262.8	13	HAZ[1]
T-30	Weld bead left on	261.6	20	Parent metal
T-31	Weld bead left on	251.3	20	Parent metal
T-32	Weld bead left on	253.4	22	Parent metal
Avg		257.3	19	
T-6	Weld bead ground off	253.7	10	Weld metal
T-7	Weld bead ground off	256.8	14	Weld metal
T-8	Weld bead ground off	256.4	12	Weld metal
Avg		255.6	12	
T-13	Single repair bead off	250.6	12	Weld metal
T-14	Single repair bead off	252.4	10	Weld metal
T-15	Single repair bead off	255.4	12	Weld metal
T-16	Single repair bead off	255.4	11	Weld metal
Avg		253.5	11	
T-20	Multiple repair bead off	255.4	12	Weld metal
T-24	Multiple repair bead off	255.3	8	Weld metal
T-25	Multiple repair bead off	250.9	10	Weld metal
Avg		253.9	10	

NOTE:
1. Heat-affected zone

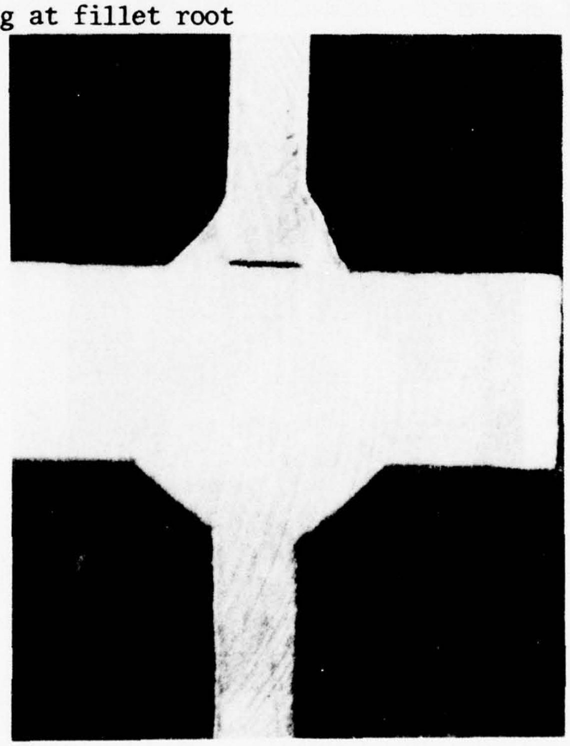
Table 26

ROOM TEMPERATURE TENSILE TEST RESULTS FOR CORNER PENETRATION FILLET-WELDED AF1410 ALLOY STEEL (SYMMETRICAL JOINT)

Specimen Ident	Specimen Condition	Max Stress ksi[1]	Failure Location
WT-1	0.200 in. nom	179.2	Fillet[2]
WT-2	Leg-corner	166.2[3]	Fillet[2]
WT-3	Penetration	234.9	Fillet[2]
WT-4	Fillet-welded	226.3	Fillet[2]
WT-5	Cruciforms	226.2	Fillet[2]
Avg		206.6	

NOTES:

1. Maximum stress on the load carrying leg
2. Shear failure in both fillets
3. Cracking at fillet root



WT-3

Table 27

ROOM TEMPERATURE TENSILE TEST RESULTS FOR CORNER PENETRATION FILLET-WELDED AF1410 ALLOY STEEL (SYMMETRICAL JOINT)

Specimen Ident	Specimen Condition	Max Stress ksi[1]	Failure Location
WH-1	0.375" in. nom	247.5	Heat-affected
WH-2	Leg-corner	246.2	Zone (across
WH-3	Penetration	247.0	load carrying
WH-4	Fillet-welded	244.0	leg)
WH-5	Cruciforms	246.4	
Avg.		246.2	

NOTE:

1. Maximum stress on the load carrying leg

WH-4

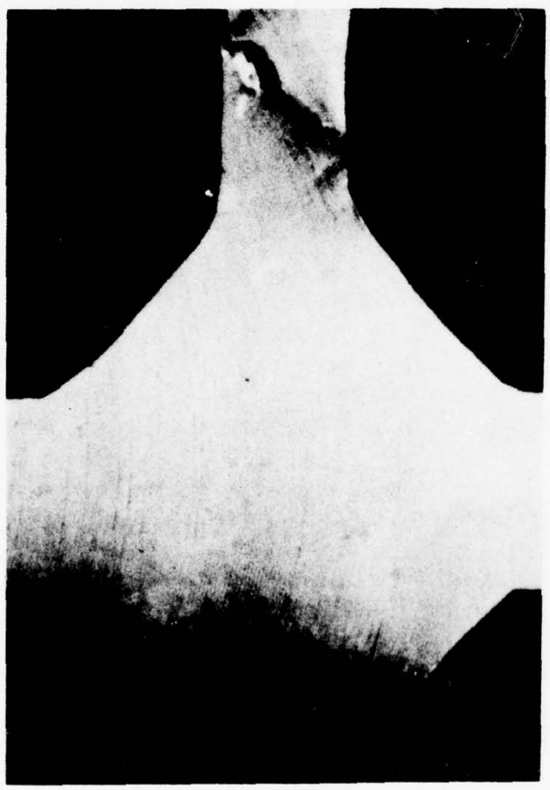
Table 28

ROOM TEMPERATURE TENSILE TEST RESULTS FOR FULL PENETRATION FILLET-WELDED AF1410 ALLOY STEEL (SYMMETRICAL JOINT)

Specimen Ident	Specimen Condition	Max Stress ksi[1]	Failure Location
WS-1	0.375 in. nom	247.3	Heat-affected zone
WS-2	Leg - full	251.8	Heat-affected zone
WS-3	Penetration	253.6	Heat-affected zone
WS-4	Fillet-welded	249.6	Heat-affected zone
Avg	Cruciforms	250.6	

NOTE:

1. Maximum stress on the load carrying leg



WS-2

Table 29

ROOM TEMPERATURE TENSILE TEST RESULTS FOR FULL PENETRATION FILLET-WELDED AF1410 ALLOY STEEL (ASYMMETRICAL JOINT)

Specimen Ident	Specimen Condition	Max Stress ksi[1]	Failure Location
WA-1	0.375 in. nom	274.2	Heat-affected zone
WA-2	Leg - full	248.3	Heat-affected zone
WA-3	Penetration	249.1	Heat-affected zone
WA-4	Fillet-welded	247.0	Heat-affected zone
WA-5	Cruciforms	253.5	Heat-affected zone
Avg		254.4	

NOTE:

1. Maximum stress on the load carrying leg

WA-5

Table 30

ROOM TEMPERATURE CHARPY IMPACT PROPERTIES FOR BUTT-WELDED AF1410 ALLOY STEEL

Specimen Identification	Notch Location	Charpy Impact Strength (foot-pounds)
C1-1	Weldment	57.0
C1-2	Weldment	50.5
C1-3	Weldment	45.5
C1-4	Weldment	46.0
C1-5	Weldment	41.5
C1-6	Weldment	50.5
C1-7	Weldment	46.5
C1-8	Weldment	52.5
C1-9	Weldment	46.5
C1-10	Weldment	49.5
C1-11	Weldment	50.5
C1-12	Weldment	59.5
Avg		50.5
C2-1	Heat-affected zone	45.0
C2-2	Heat-affected zone	38.0
C2-3	Heat-affected zone	37.5
C2-4	Heat-affected zone	39.0
C2-5	Heat-affected zone	42.0
C2-6	Heat-affected zone	38.0
C2-7	Heat-affected zone	47.5
C2-8	Heat-affected zone	50.5
C2-9	Heat-affected zone	49.5
C2-10	Heat-affected zone	45.0
C2-11	Heat-affected zone	47.5
C2-12	Heat-affected zone	54.5
Avg		44.5

Because of this wide scatter in individual test results, the difference shown in average value between the weldment and heat-affected zone is probably not a significant amount.

Fracture Toughness, K_{I_C}

The values for K_{Ic} obtained for the weld metal and the heat-affected zone are shown in table 31 The K_{Ic} values obtained at room temperature for the weld metal and heat-affected zone were comparable to the values obtained for parent metal. A single weld repair does not adversely affect the fracture toughness of the weld. The lower test temperature (-65° F) resulted in a reduction in toughness, with the effect being greater in the heat-affected zone than in the weld metal.

Butt Weld Fatigue

Data obtained for bead-on specimens at the ratio of minimum to maximum cylic stress (R) of +0.05 are shown in table 32 and graphically as an S-N curve in figure 53. The results of bead-on tests at R = +0.5 and -1.0 are shown in tables 33 and 34 and figures 54 and 55 , respectively. A comparison of these three bead-on S-N curves is presented in figure 56 where the three generated S-N curves are shown together.

Similarly, the results obtained for the bead-off butt weld specimen are shown in tables 35 through 37 and figures 57 through 59 . To compare the effect of R value on the S-N curve for bead-off specimen, these three curves have been replotted in figure 60 .

The data for single and multiple repair welds are tabulated in tables 38 and 39 plotted as S-N curves in figures 61 and 62 . To compare the effect of repair welding on fatigue, these two S-N curves are plotted together with the S-N curve for welds with no repairs (from figure 57) and shown in figure 63 .

It was observed that the majority of the bead-off specimen failures originated subsurface at small, discrete discontinuities (porosity of the order of a few thousandths of an inch in diameter was observed at the origin point in some instances). To ascertain whether subsurface fatigue initiation by such small discontinuities is a characteristic of these weld deposits or the result of specimen geometry (rectangular cross section), a group of round-bar fatigue specimens was fabricated utilizing the same procedures employed to weld and fabricate the rectangular specimens. The fatigue test results obtained with these round-bar specimens are shown in table 40 and figure 64 . Half of the eight specimens exhibited subsurface failure

Table 31

FRACTURE TOUGHNESS PROPERTIES (K_{Ic}) FOR BUTT-WELDED AF1410 ALLOY STEEL

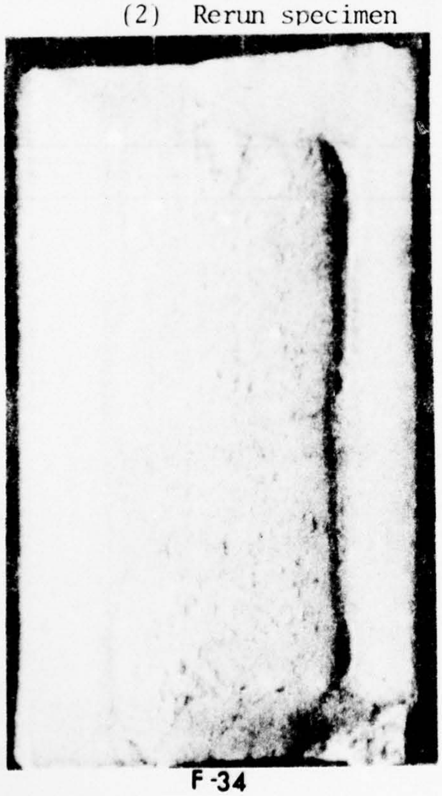
Specimen Identification	Test Temperature	Crack Location	Special Processing	K_{Ic} ksi $\sqrt{in.}$
K1	Room temperature	Weld	-	128.5
K2	Room temperature	Weld	-	155.8
K5	Room temperature	Weld	Single repair	150.0
Avg				144.8
K6	Room temperature	Heat-affected zone	-	149.4
K7	Room temperature	Heat-affected zone	-	146.3
Avg				147.9
K3	-65° F	Weld	-	131.7
K4	-65° F	Weld	-	134.4
Avg				133.1
K8	-65° F	Heat-affected zone	-	120.1
K9	-65° F	Heat-affected zone	-	129.2
Avg				124.7

Table 32

ROOM TEMPERATURE AXIAL FATIGUE TEST RESULTS FOR FUSION-WELDED (BUTT JOINT) AF1410 ALLOY STEEL (BEAD LEFT ON) F_{tu} = 250.4 ksi

Specimen Ident	Weld Orientation	Stress Concentration	R Factor	Stress ksi	% F_{tu}	Cycles to Failure	Failure Location
F-34	Transverse	K_t = 1.0	+0.05	126.0	50.3	11,000	(1)
F-37	To load	(Bar design)	↓	100.8	40.3	25,000	(1)
F-38	↓	↓	↓	75.6	30.2	59,000	(1)
F-40	↓	↓	↓	50.4	20.3	242,000	(1)
F-43	↓	↓	↓	37.8	15.1	10,042,000	No failure
F-44	↓	↓	↓	47.9	19.1	10,000,000	No failure
F-43(2)	↓	↓	↓	45.4	18.2	10,076,000	No failure
F-43(2)	↓	↓	↓	60.5	24.2	241,000	(1)
F-44(2)	↓	↓	↓	55.4	22.1	12,849,000	No failure
F-44(2)	↓	↓	↓	68.0	27.2	398,000	(1)

NOTES:
(1) Edge of Weld bead/HAZ
(2) Rerun specimen



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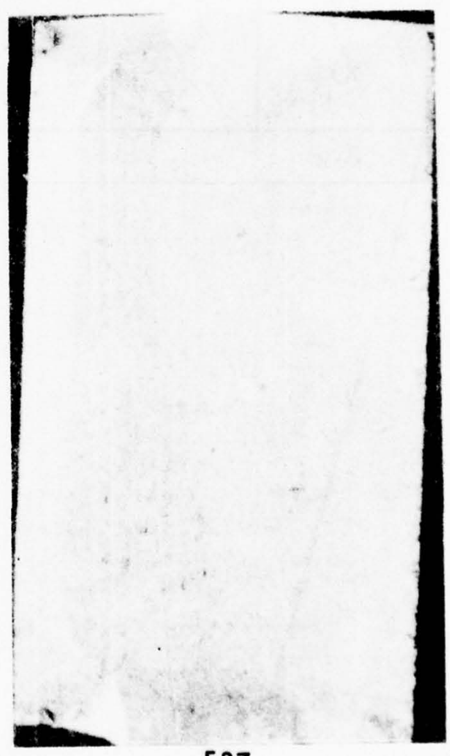

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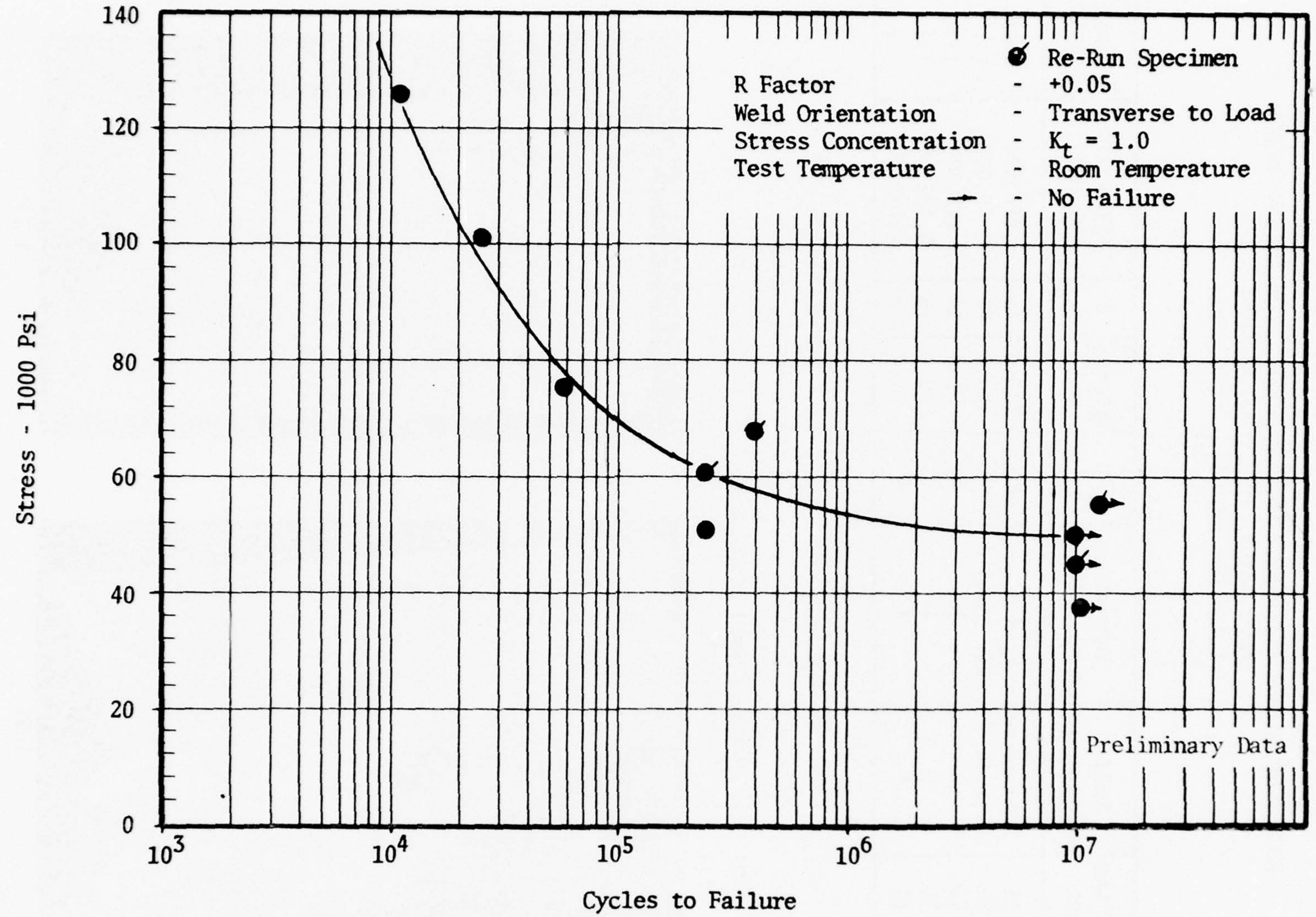


Figure 53 Room Temperature Axial Fatigue Test Results for Fusion-Welded (Butt Joint) AF1410 Alloy Steel (Bead Left On)

Table 33

ROOM TEMPERATURE AXIAL FATIGUE TEST RESULTS FOR FUSION-WELDED (BUTT JOINT) AF1410 ALLOY STEEL (BEAD LEFT ON) F_{tu} = 250.4 ksi

Specimen Ident	Weld Orientation	Stress Concentration	R Factor	Stress ksi	% F_{tu}	Cycles To Failure	Failure Location
F-31	Transverse	K_t = 1.0	+0.5	113.4	45	152,000	Weld
F-32	To load	(Bar design)	↓	100.8	40	60,000	(1)
F-33	↓	↓	↓	75.6	30	427,000	(1)
F-36	↓	↓	↓	50.4	20	3,463,000	(1)
F-46	↓	↓	↓	45.4	18	8,452,000	(2)

NOTES: (1) Edge of weld bead/HAZ
(2) Parent metal

F-31

F-32

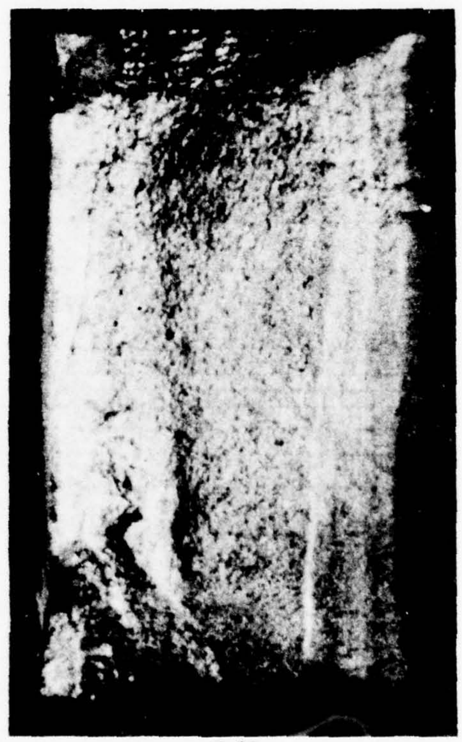
Table 34

ROOM TEMPERATURE AXIAL FATIGUE TEST RESULTS FOR FUSION-WELDED
(BUTT JOINT) AF1410 ALLOY STEEL
(BEAD LEFT ON) F_{tu} = 250.4 ksi

Specimen Ident	Weld Orientation	Stress Concentration	R Factor	Stress ksi	% F_{tu}	Cycles To Failure	Failure Location
F-39	Transverse	K_t = 1.0	-1.0	88.2	35.2	25,000	(1)
F-41	To load	(Bar design)	↓	63.0	25.2	40,000	(1)
F-42	↓	↓	↓	45.4	18.1	306,000	(1)
F-45	↓	↓	↓	37.8	15.1	6,410,000	(2)
F-47	↓	↓	↓	50.4	20.1	336,000	(1)

NOTES:
(1) Edge of weld bead/HAZ
(2) Grip failure


F-39


F-41

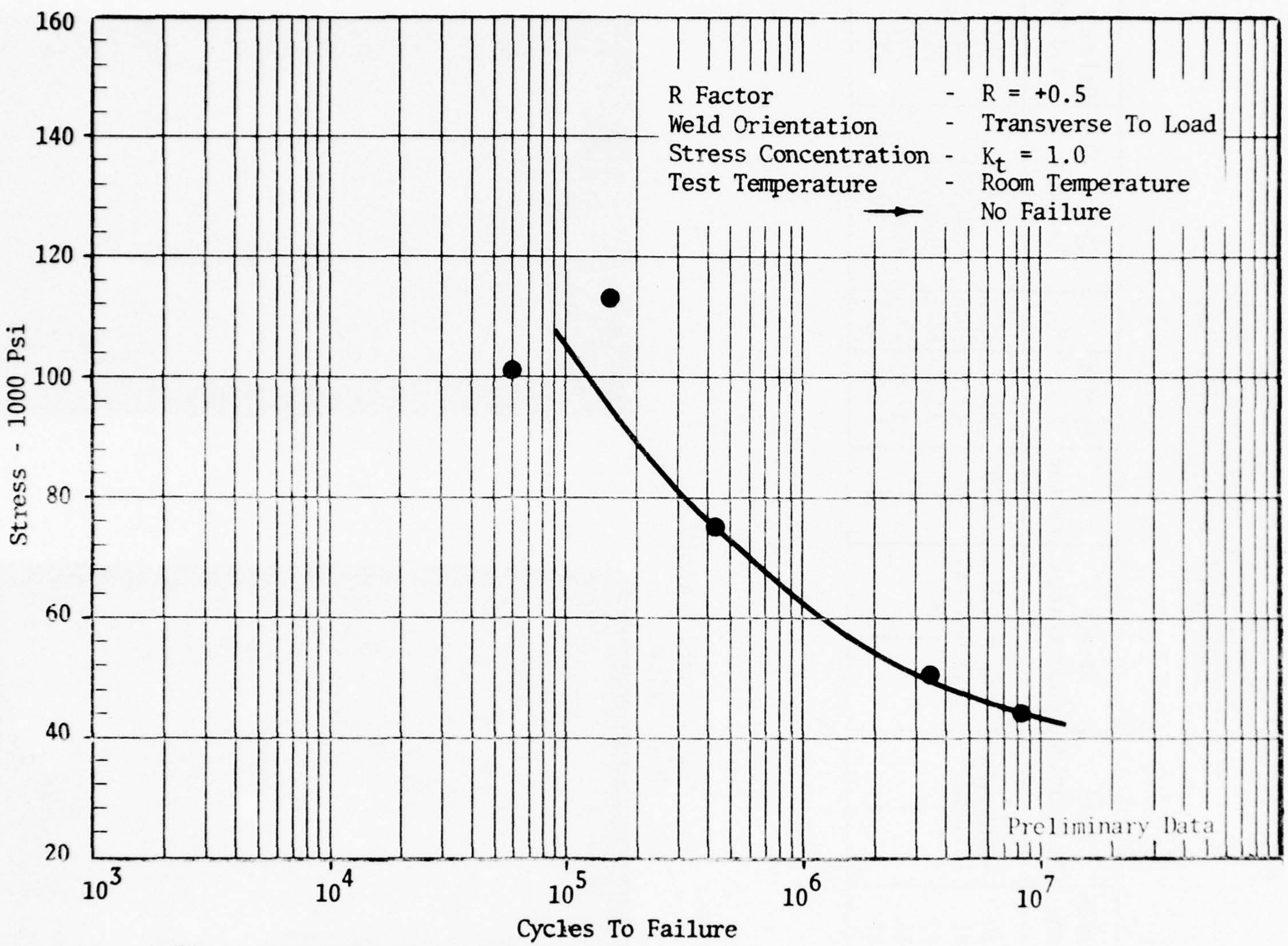


Figure 54 Room Temperature Axial Fatigue Test Results for Fusion Weld (Butt Joint) AF1410 Alloy Steel (Bead Left On)

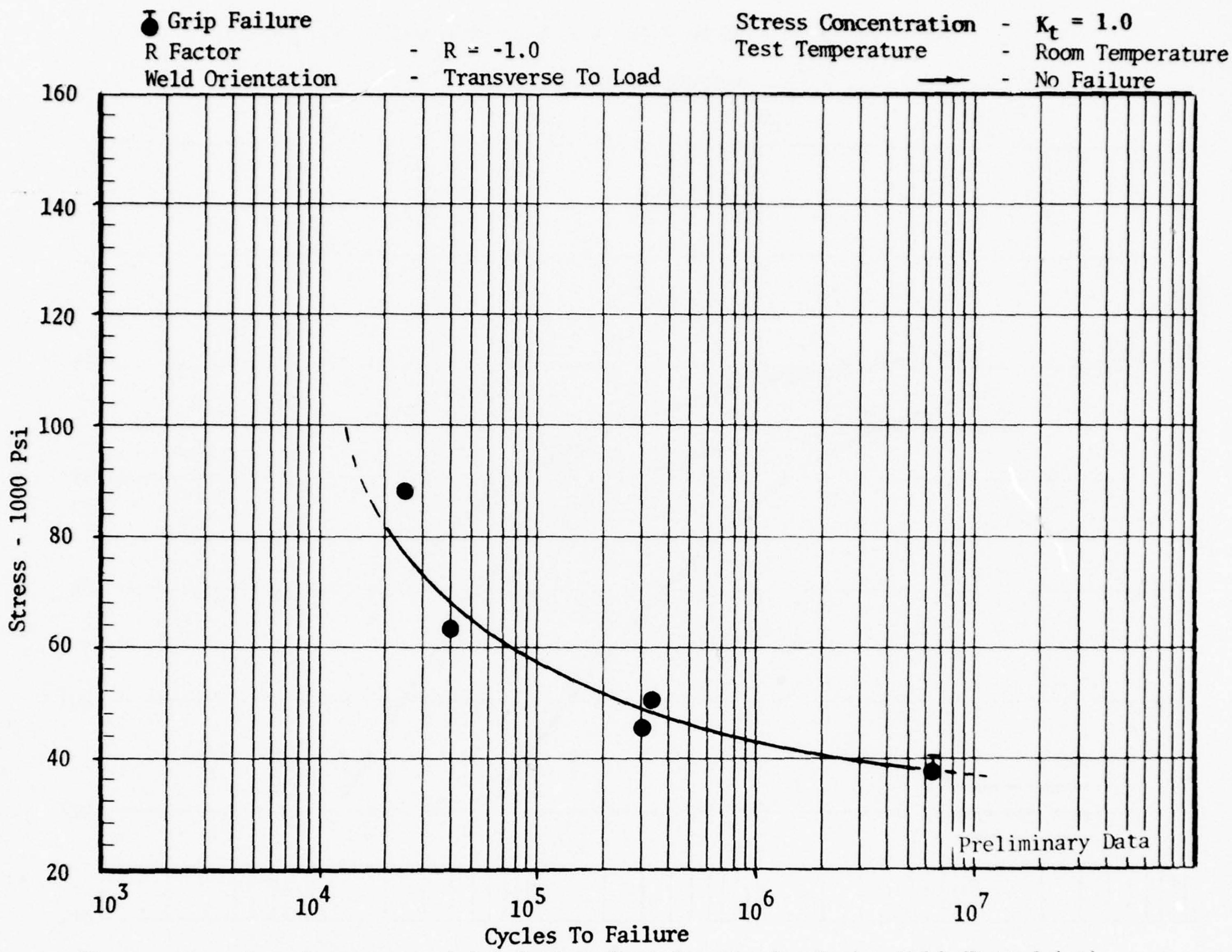


Figure 55 Room Temperature Axial Fatigue Test Results for Fusion Weld (Butt Joint) AF1410 Alloy Steel (Bead Left On)

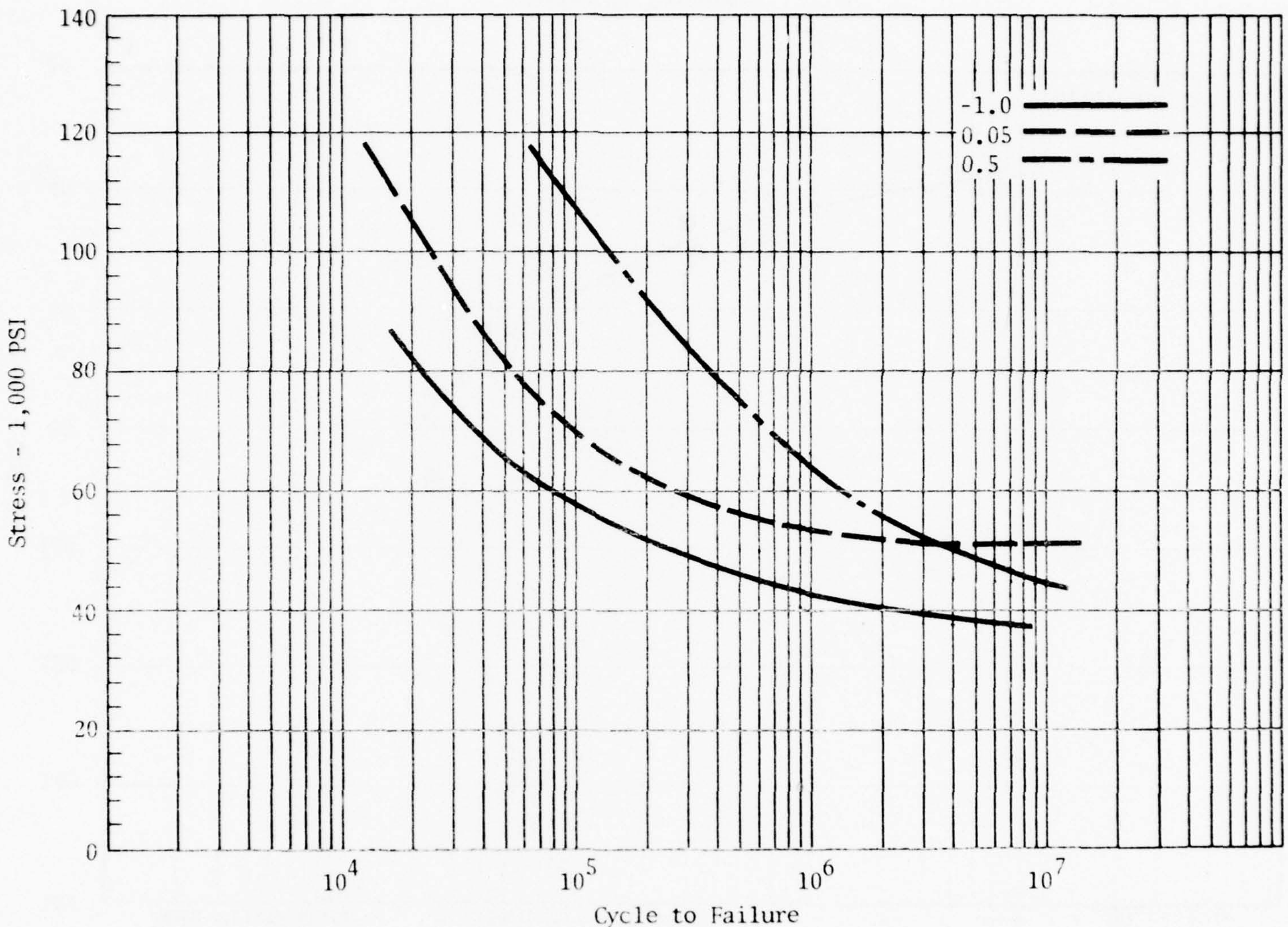


Figure 56 Effect of R On S-N Curve of Butt Welds (Bead On)

Table 35

ROOM TEMPERATURE AXIAL FATIGUE TEST RESULTS FOR FUSION-WELDED
(BUTT JOINT) AF1410 ALLOY STEEL
(BEAD OFF) F_{tu} = 232.2 ksi

Specimen Ident	Weld Orientation	Stress Concentration	R Factor	Stress ksi	% F_{tu}	Cycles To Failure	Failure Location
F-8	Transverse To load	K_t = 1.0 (Bar design)	+0.05	138.0	59	78,000	Weld[2]
F-9	↓	↓	↓	115.0	49	151,000	Weld[2]
F-10	↓	↓	↓	161.0	69	100,000	Weld[2]
F-11	↓	↓	↓	92.0	40	425,000	Weld[2]
F-12	↓	↓	↓	80.5	35	64,000	Weld[1]
F-13	↓	↓	↓	69.0	30	493,000	Weld[2]
F-15	↓	↓	↓	64.4	28	10,414,000 →[3]	
F-16	↓	↓	↓	184.0	79	13,870	Weld[1]

NOTES:

(1) Fatigue initiation at corner
(2) Internal fatigue initiation
(3) → No failure

F8

F13

F12

Table 36

ROOM TEMPERATURE AXIAL FATIGUE TEST RESULTS FOR FUSION-WELDED
(BUTT JOINT) AF1410 ALLOY STEEL
(BEAD OFF) F_{tu} = 232.2 ksi

Specimen Ident	Weld Orientation	Stress Concentration	R Factor	Stress ksi	% F_{tu}	Cycles To Failure	Failure Location
F-1	Transverse To load	K_t = 1.0 (Bar design)	+0.5	126.5	55	369,000	Weld(1)
F-2	↓	↓	↓	149.5	64	49,000	Weld(1)
F-3	↓	↓	↓	138.0	59	29,000	Weld(1)
F-5	↓	↓	↓	161.0	69	68,000	Weld(1)
F-6	↓	↓	↓	82.8	36	10,033,000+	No failure
F-7	↓	↓	↓	92.0	40	4,088,000	Weld(1)

NOTE:
(1) Internal fatigue initiation


F-1


F-2

Table 37

ROOM TEMPERATURE AXIAL FATIGUE TEST RESULTS FOR FUSION-WELDED (BUTT JOINT) AF1410 ALLOY STEEL (BEAD OFF) F_{tu} = 232.2 ksi

Specimen Ident	Weld Orientation	Stress Concentration	R Factor	Stress ksi	% F_{tu}	Cycles To Failure	Failure Location
F-17	Transverse To load	K_t = 1.0 (Bar design)	-1.0	80.5	34.7	658,000	Weld (1)
F-18	↓	↓	↓	103.5	44.6	242,000	Weld (1)
F-19				69.5	29.9	380,000	Weld (1)
F-20				126.5	55.5	16,380	Weld
F-21				57.5	24.8	10,033,000 →	No failure
F-22				92.0	39.6	148,000	Weld (3)
F-21 (2)				64.4	27.7	5,735,000	Weld (1)

NOTES:

(1) Internal fatigue initiation
(2) Rerun
(3) Surface initiation

F-18

F17

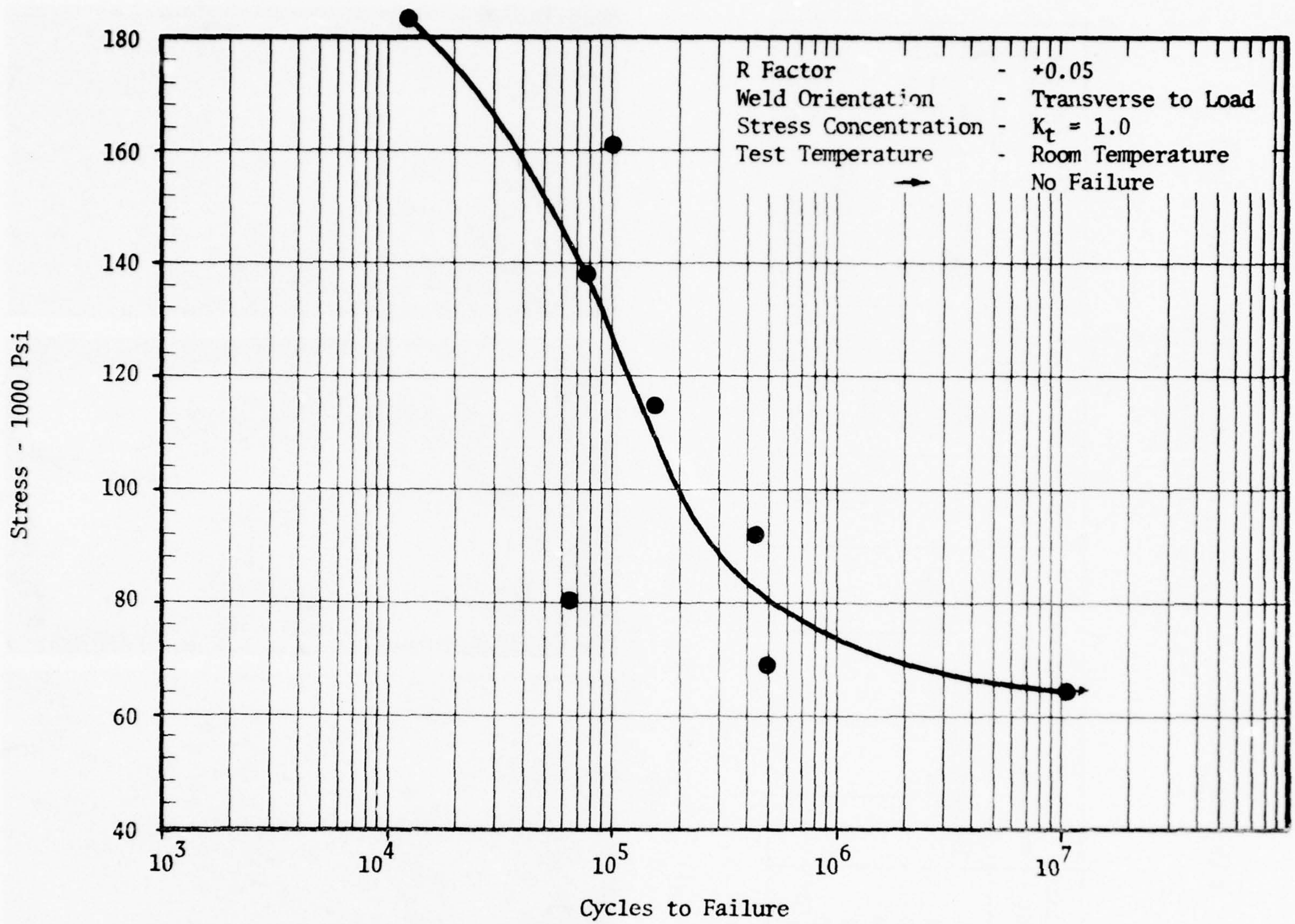


Figure 57 Room Temperature Axial Fatigue Test Results for Fusion Welded (Butt Joint) AF1410 Alloy Steel (Bead Off)

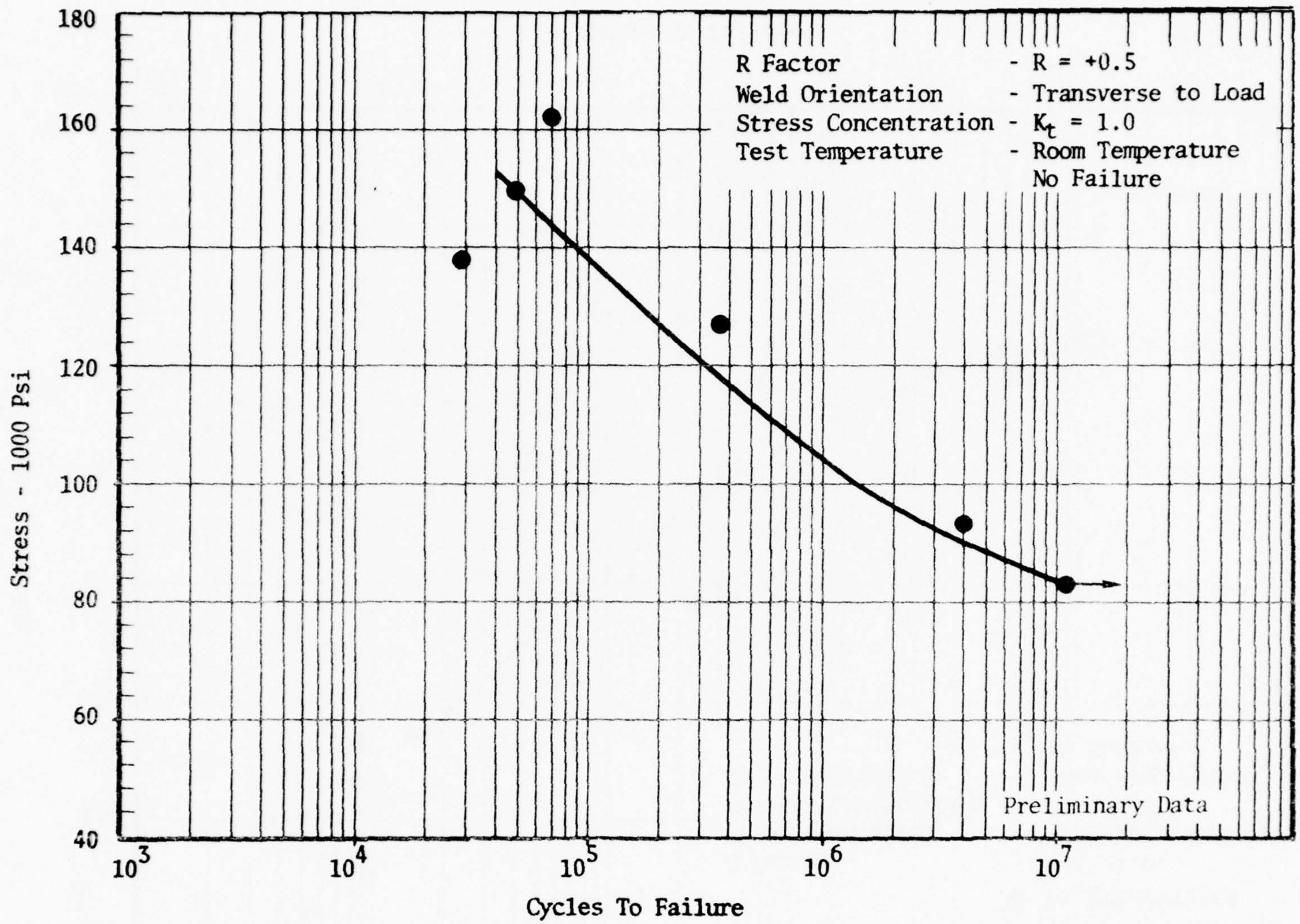


Figure 58 Room Temperature Axial Fatigue Test Results for Fusion Welded (Butt Joint) AF1410 Alloy Steel (Bead Off)

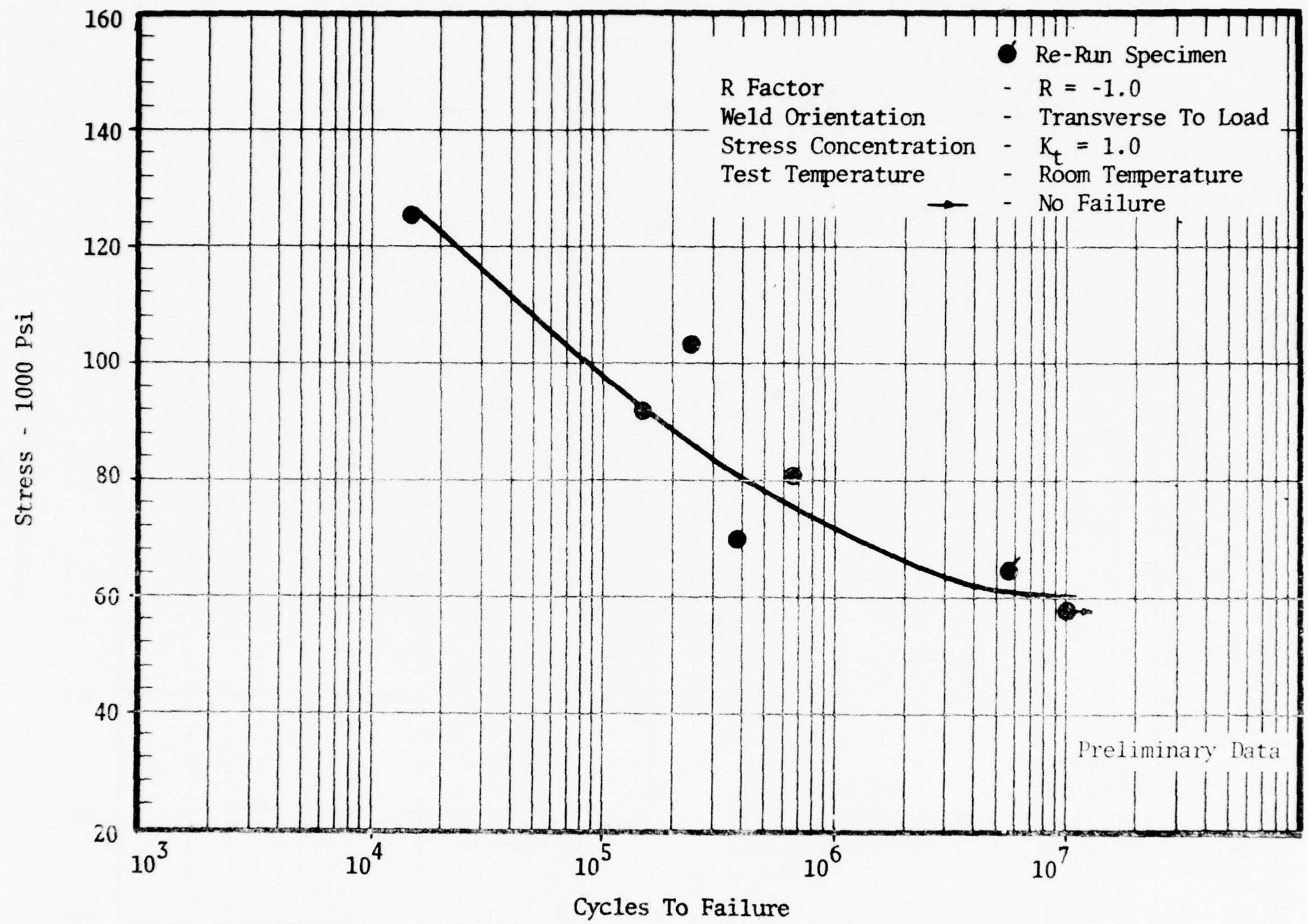


Figure 59 Room Temperature Axial Fatigue Test Results for Fusion Welded (Butt Joint) AF1410 Alloy Steel (Bead Off)

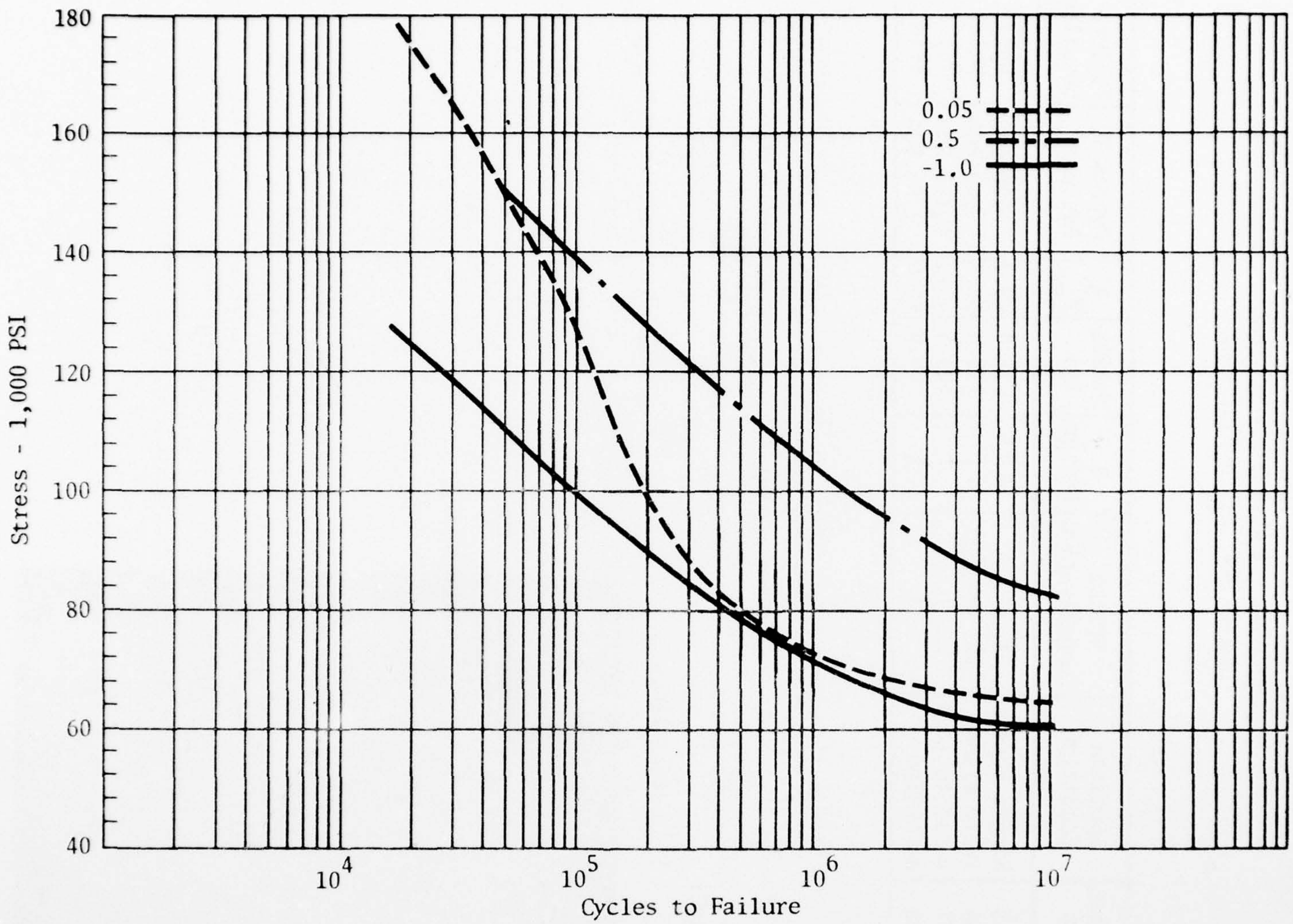


Figure 60 Effect of R On S-N Curve of Butt Welds (Bead Off)

Table 38

ROOM TEMPERATURE AXIAL FATIGUE TEST RESULTS FOR FUSION-WELDED (BUTT JOINT) AF1410 ALLOY STEEL (BEAD OFF) F_{tu} = 235.9 ksi

Specimen Ident	Specimen Condition	Stress Concentration	R Factor	Stress ksi	% F_{tu}	Cycles To Failure	Failure Location
F-23	Single repair	K_t = 1.0	+0.05	115.0	48.7	280,000	Weld
F-26	(Weld trans-	(Bar design)	↓	138.0	58.5	103,700	Weld
F-27	verse to load	↓		103.5	43.9	1,425,000	(1)
F-28	direction)			96.6	40.9	95,000	Weld

NOTE:

(1) Grip failure

F23

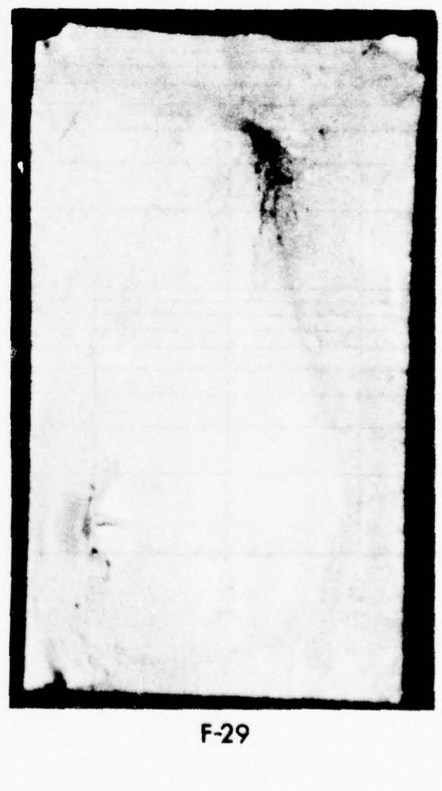
Table 39

ROOM TEMPERATURE AXIAL FATIGUE TEST RESULTS FOR FUSION-WELDED (BUTT JOINT) AF1410 ALLOY STEEL (BEAD OFF) F_{tu} = 239.3 ksi

Specimen Ident	Specimen Condition	Stress Concentration	R Factor	Stress ksi	% F_{tu}	Cycles To Failure	Failure Location
F-4	Multiple Repair (weld transverse to load direction)	K_t = 1.0 (Bar design)	+0.05	115.0	48	43,000	Weld
F-14	↓	↓	↓	92.0	38	78,000	Weld(1)
F-29	↓	↓	↓	57.5	24	548,000	Weld(1)
F-30	↓	↓	↓	46.0	19	10,000,000→	(2)

NOTES:
(1) Internal fatigue initiation
(2) No failure


F-4


F-29

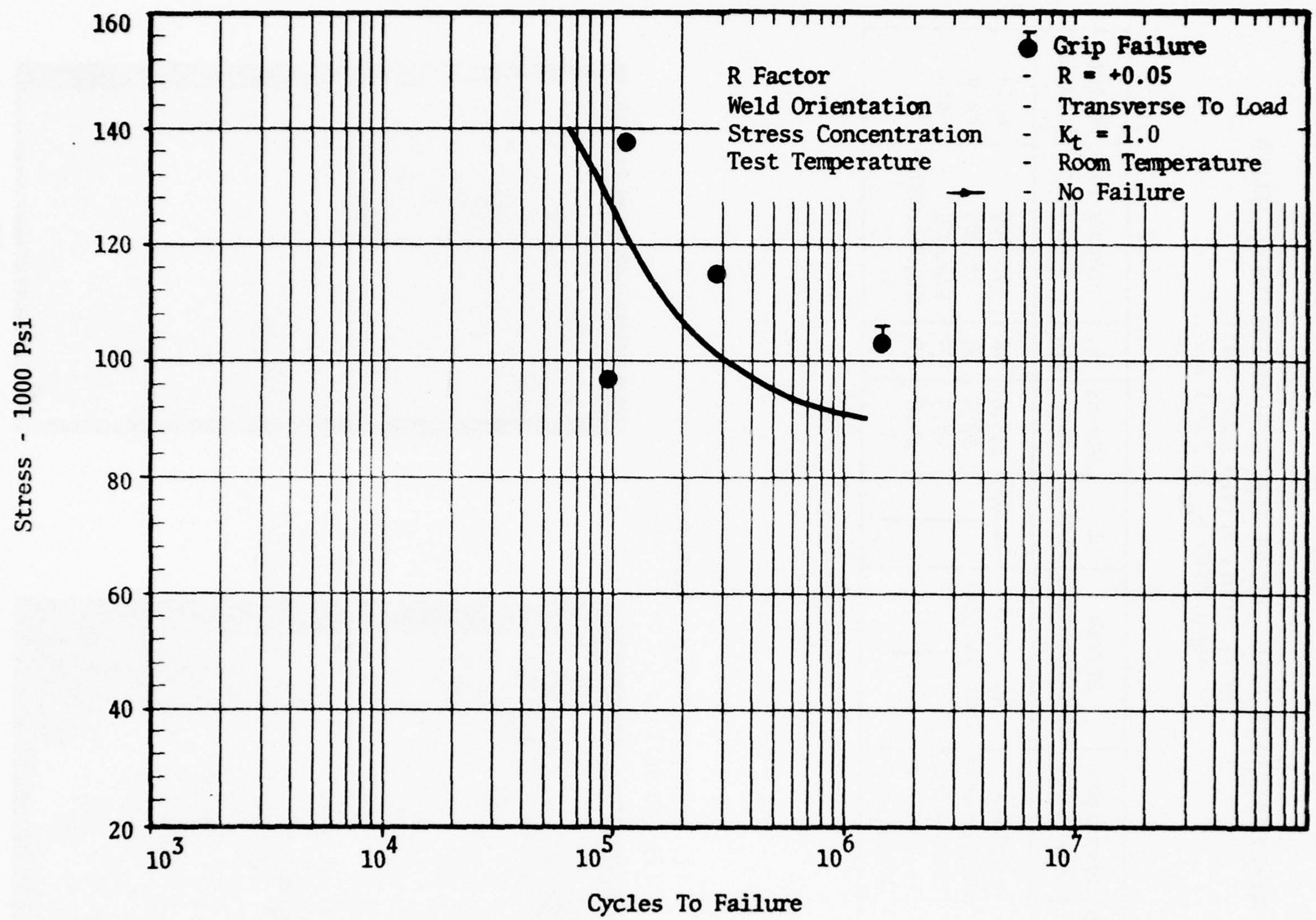


Figure 61 Room Temperature Axial Fatigue Test Results for Single Repair Fusion Welded (Butt Joint) AF1410 Alloy Steel (Bead Off)

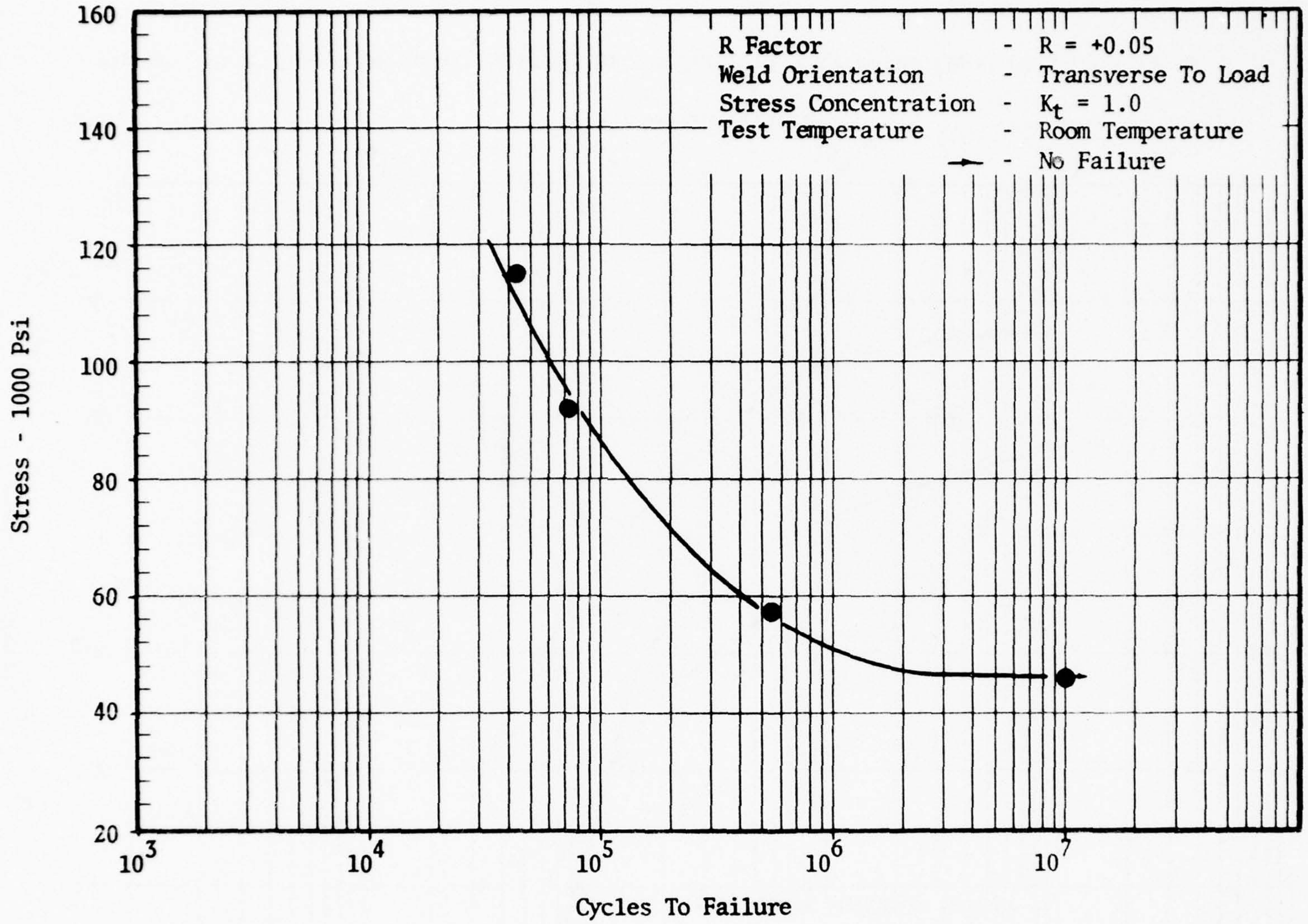


Figure 62 Room Temperature Axial Fatigue Test Results for Multiple Repair Fusion Welded (Butt Joint) AF1410 Alloy Steel (Bead Off)

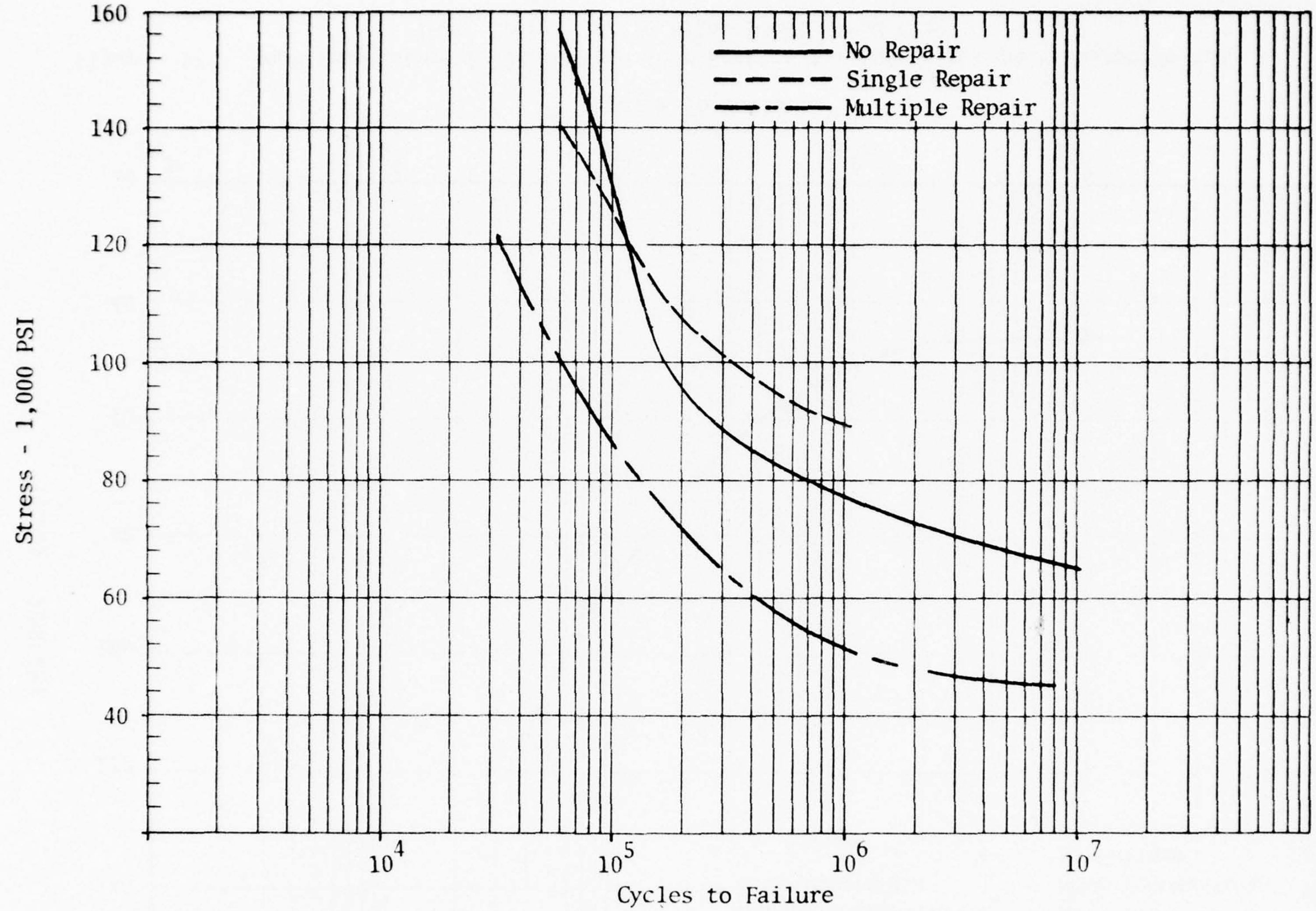


Figure 63 Effect of Repair Welding On S-N Curve of Butt Welds (Bead Off), R = +0.05

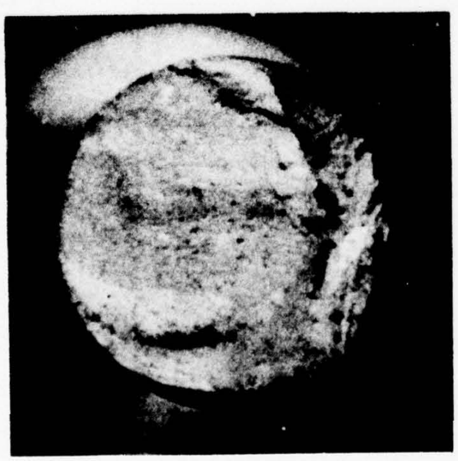
Table 40

ROOM TEMPERATURE AXIAL FATIGUE TEST RESULTS FOR FUSION-WELDED
(BUTT JOINT) AF1410 ALLOY STEEL
(BEAD OFF - ROUND FATIGUE BARS)

Specimen Ident	Weld Orientation	Stress Concentration	R Factor	Stress ksi	Cycles To Failure	Failure Location
F51-1	Transverse To load	K_t = 1.0 (Bar design)	+0.05	96.0	10,611,000→	No failure
F51-2				168.0	43,000	Weld
F51-3				180.0	54,000	Weld
F51-4				160.8	19,000	(2)
F51-5				153.6	50,000	(2)
F51-6				132.0	174,000	(2)
F51-7				110.4	347,000	(2)
F51-8				100.8	83,000	Weld
F51-1 (1)				120.0	700,000→	No failure
F51-1 (1)				192.0	11,000	Weld

NOTE:

(1) Rerun
(2) Weld - internal initiation



F51-3

F51-6

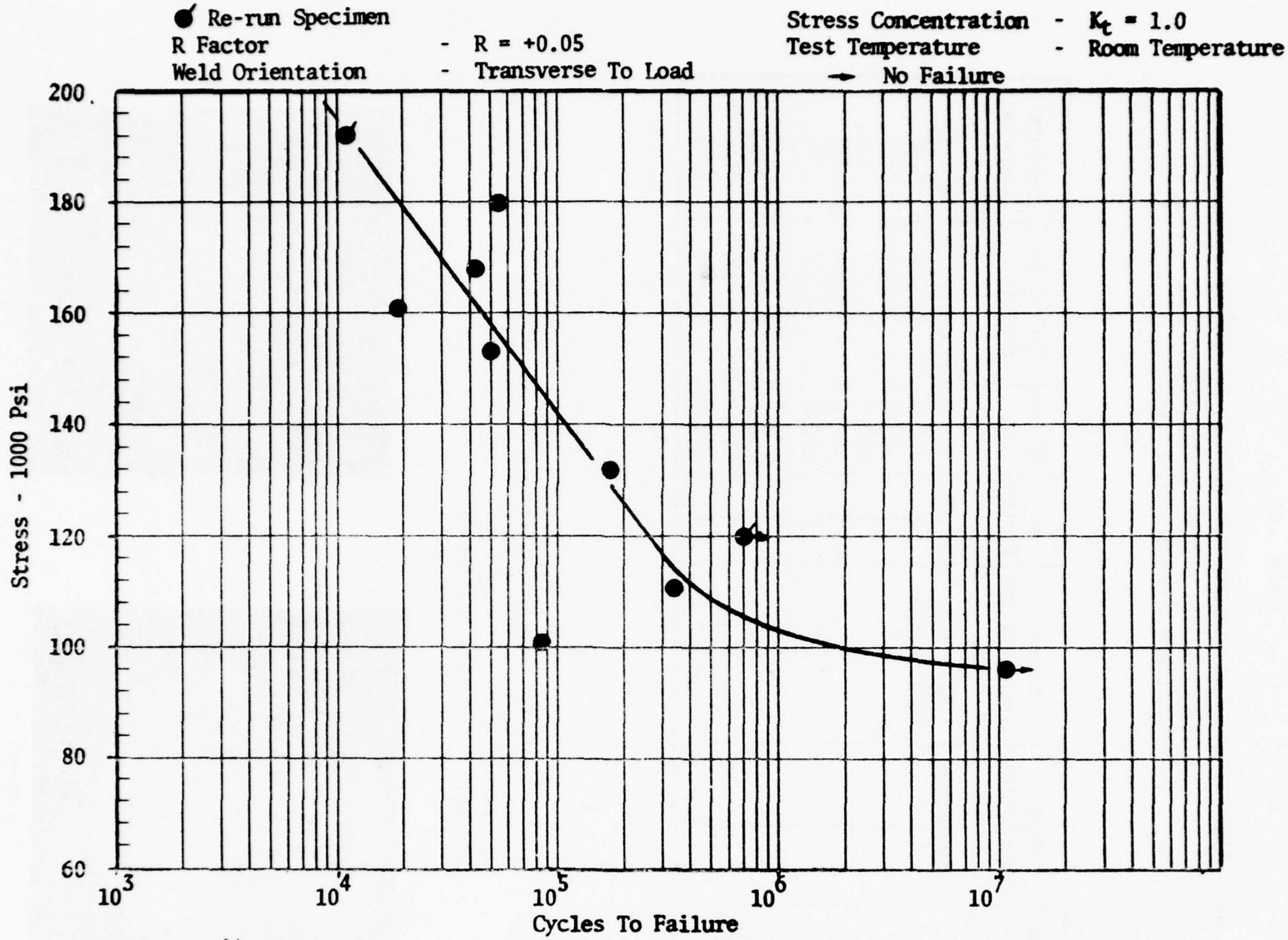


Figure 64 . Room Temperature Axial Fatigue Test Results for Fusion Welded (Butt Joint) AF1410 Alloy Steel (Bead Off - Round Fatigue Bars)

origins, and it was concluded the behavior was independent of specimen geometry. Subsurface fatigue origins immediately below the specimen surface are not unusual in high-strength steels. The origins observed here were well below the surface, some approximating the midpoint of thickness, and were not of the near-surface type frequently observed.

Fillet Weld Fatigue

Fatigue test results for the partial-penetration fillet weld specimens with the 0.200-inch-thick leg are shown in table 41 and plotted as an S-N curve in figure 65. Failure in most cases originated at the root area at the notch created by the intentional lack of penetration. One specimen, identified WT-13, deviated from the general failure path and failed by a combination of weld and HAZ fracture (see photo in table 47 . This change in failure mode did not affect the fatigue life, i.e., the point for specimen WT-13 is on the S-n curve generated by the specimens exhibiting failure through the root area.

Results of the tests on partial-penetration specimens with a 0.375-inch-thick leg are shown in table 42 and figure 66. Failures occurred in half the specimens in the HAZ, though failure location showed no apparent effect on fatigue life. The fatigue life of the 0.375-inch-thick specimens is slightly superior to the 0.200-inch-thick specimens. Full-penetration fillet weld fatigue results are presented in table 43 and figure 67. These specimens all failed in the HAZ as would be anticipated for a full-penetration weld. The S-N curve for these specimens are similar to the curve for 0.375 partial penetration specimens at the higher stress end of the curve, and shows improved fatigue life at lifetimes in excess of 10^6 cycles.

The data in figure 67 were derived on specimens with a symmetrical weld, i.e., welded an equal amount from both sides of the leg producing two equal-sized fillet welds. The effect of an asymmetrical weld, one in which all the welding is performed from one side of the leg, is shown in the results in table 44 and figure 68. No marked difference in fatigue life of the two weld geometries is apparent in these data.

Stress Corrosion

Results of the stress corrosion testing of the weld and the HAZ are tabulated in table 45 . As observed with the parent metal tests, crack branching occurred at the higher initial stress intensities. Only one of the specimens in this series branched, specimen S10, which was the highest stress intensity employed in this group of specimens.

Table 41

ROOM TEMPERATURE AXIAL FATIGUE TEST RESULTS FOR CORNER PENETRATION FILLET-WELDED AF1410 ALLOY STEEL F_{tu} = 206.6 (SYMMETRICAL JOINT)

Specimen Ident	Specimen Condition	R Factor	Max. Stress ksi[1]	% F_{tu}	Cycles to Failure	Failure Location
WT-7	0.200 in. nom	+0.05	80.9	39.2	7,000	Fillet[3]
WT-8	leg-Corner	+0.05	61.7	29.9	23,000	Fillet[3]
WT-9	Penetration	+0.05	40.9	19.8	35,000	Fillet[3]
WT-10	Fillet-welded	+0.05	20.2	9.8	182,000	Fillet[3]
WT-11	Cruciforms	+0.05	10.0	5.8	2,190,000	Fillet[3]
WT-12		+0.05	6.1	3.0	12,052,000[2] →	
WT-13		+0.05	14.0	6.8	656,000	Fillet/leg[4]

NOTES:

(1) Maximum stress on the axial load carry leg
(2) No failure
(3) Shear (fatigue) failure in both fillets
(4) Combination of fillet weld failure (shear) propagating thru the load carrying leg

WT-7

WT-13

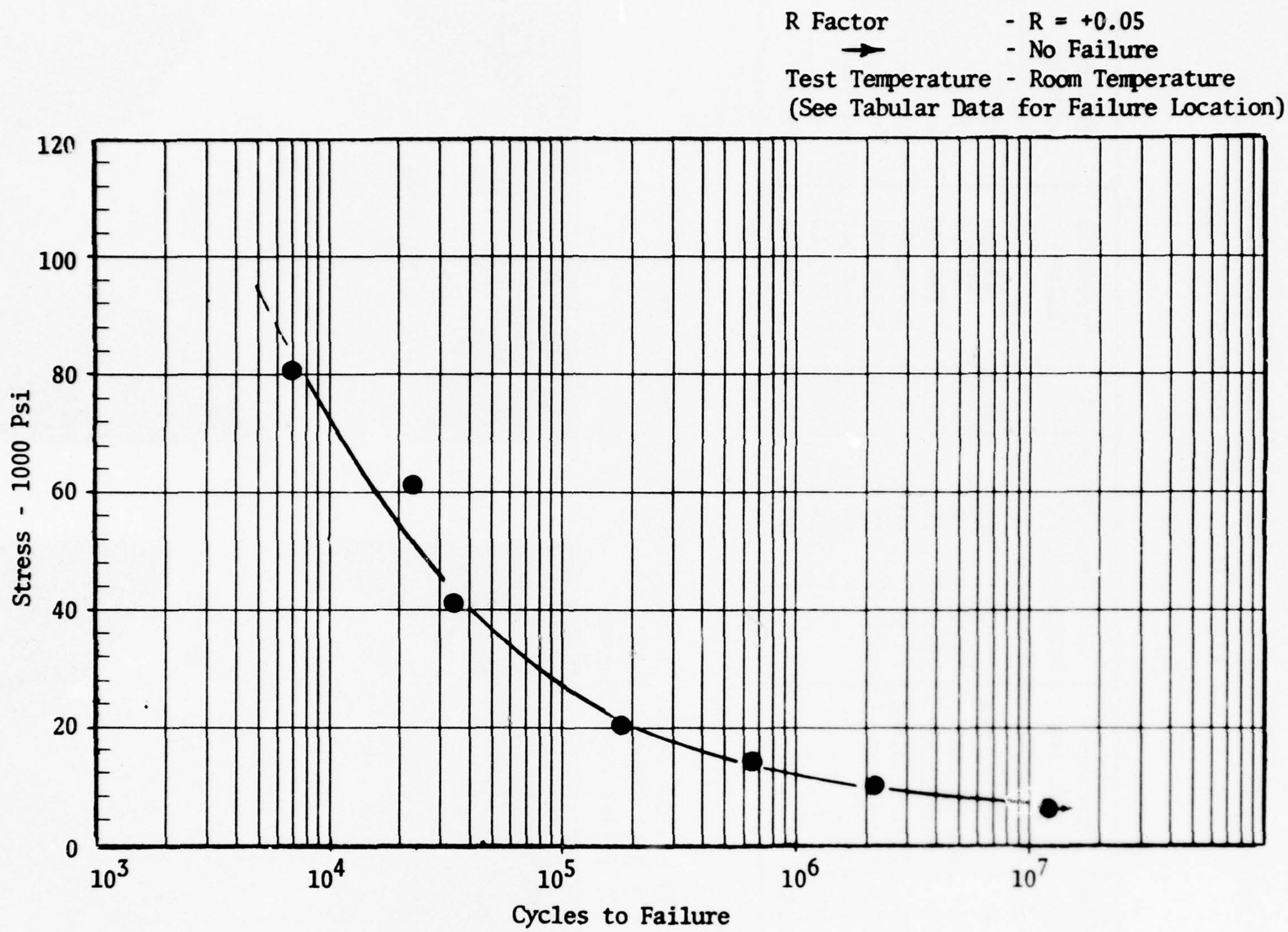


Figure 65 . Axial Tension-Tension Fatigue Test Results for (0.200 In. Nominal Leg) Corner Penetration Fillet Welded Cruciforms Fabricated From AF1410 Alloy Steel

Table 42

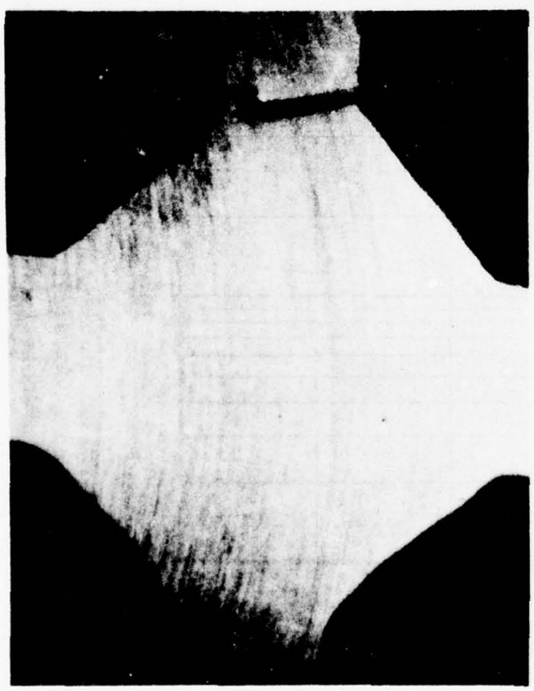
ROOM TEMPERATURE AXIAL FATIGUE TEST RESULTS FOR PARTIAL PENETRATION FILLET-WELDED AF1410 ALLOY STEEL (SYMMETRICAL JOINT)

$F_{tu} = 246.2$

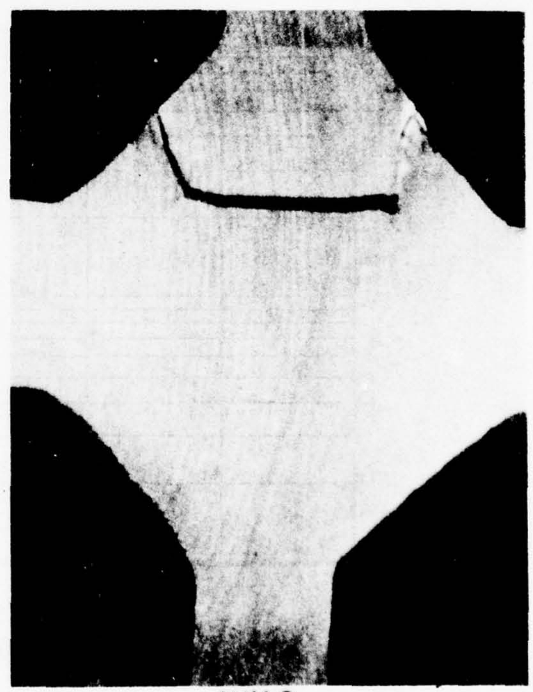
Specimen Ident.	Specimen Condition	R Factor	Max Stress ksi(1)	% F_{tu}	Cycles To Failure	Failure Location
WH-6	0.375 in. nom	+0.05	53.2	21.6	43,000	HAZ(2)
WH-7	Leg-partial	+0.05	39.2	15.9	73,000	HAZ(2)
WH-8	Penetration	+0.05	27.7	11.3	898,000	Fillet shear(3)
WH-9	Fillet-welded	+0.05	19.9	8.1	3,398,000	Fillet shear(3)
WH-10	Cruciforms	+0.05	16.1	6.5	5,328,000	Fillet shear(3)
WH-11			12.8	5.2	9,550,000	Fillet shear(3)
WH-12			33.1	13.4	334,000	HAZ
WH-13			64.4	26.2	18,000	HAZ

NOTES:

(1) Maximum stress on the axial load carrying leg
(2) Heat affected zone
(3) Fillet shear failure



WH-6



WH-8

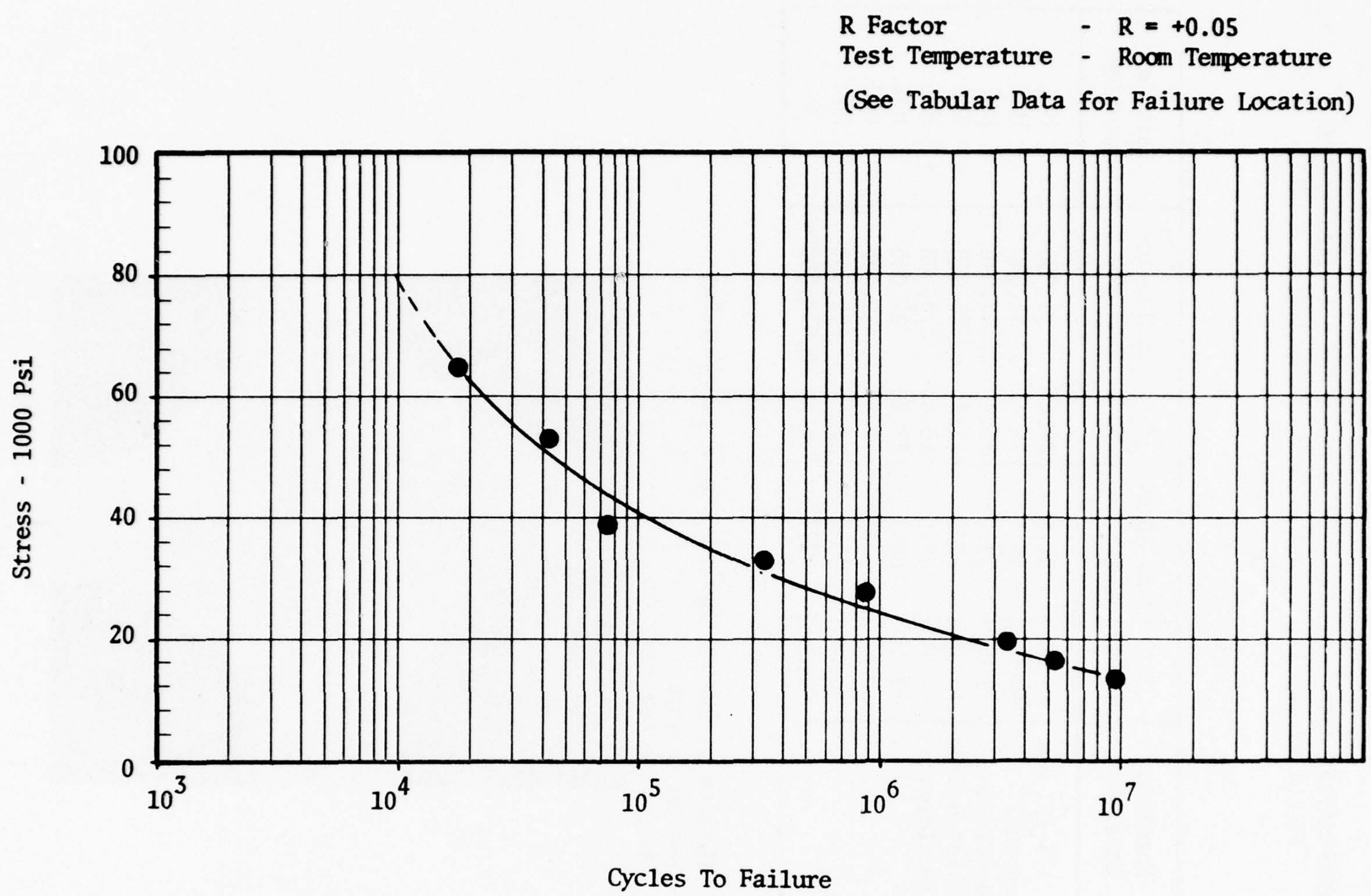


Figure 66 . Axial Tension - Tension Fatigue Test Results for (0.375 In. Nominal Leg) Partial Penetration Fillet Welded Cruciforms Fabricated From AF1410 Alloy Steel (Symmetrical Joint) WH Series

Table 43

ROOM TEMPERATURE AXIAL FATIGUE TEST RESULTS FOR FULL PENETRATION FILLET-WELDED AF1410 ALLOY STEEL (SYMMETRICAL JOINT)

$F_{tu} = 250.6$

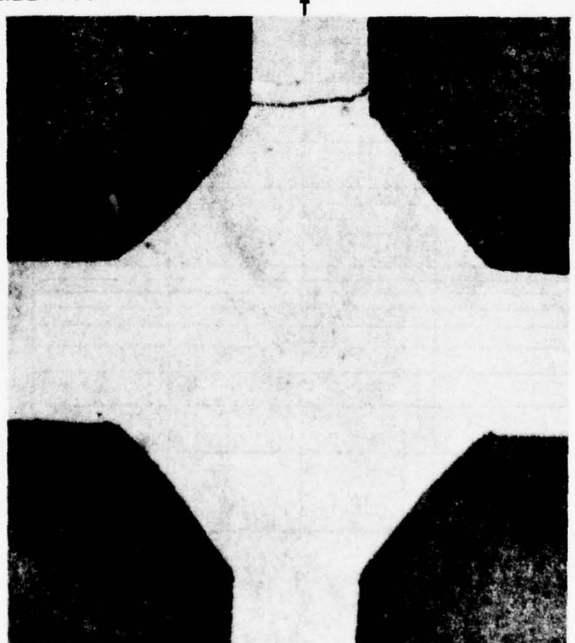
Specimen Ident	Specimen Condition	R Factor	Max. Stress ksi (1)	% F_{tu}	Cycles to Failure	Failure Location
WS-6	0.375 in. nom	+0.05	51.5	20.6	34,000	HAZ
WS-7	leg-pull	+0.05	46.1	18.4	37,000	HAZ
WS-8	Penetration	+0.05	33.2	13.2	2,185,000	HAZ
WS-9	Fillet-welded	+0.05	29.5	11.8	325,000	HAZ
WS-10	Cruciforms	+0.05	40.0	16.0	218,000	HAZ
WS-11		+0.05	68.1	27.2	27,000	HAZ
WS-12		+0.05	94.7	37.8	9,000	HAZ
WS-13		+0.05	40.7	16.2	212,000	HAZ
WS-3		+0.05	22.1	8.8	10,034,000 (2) →	

NOTES:

(1) Maximum stress on the axial load carrying leg

(2) → No failure

(3) Heat-affected zone -



WS-6

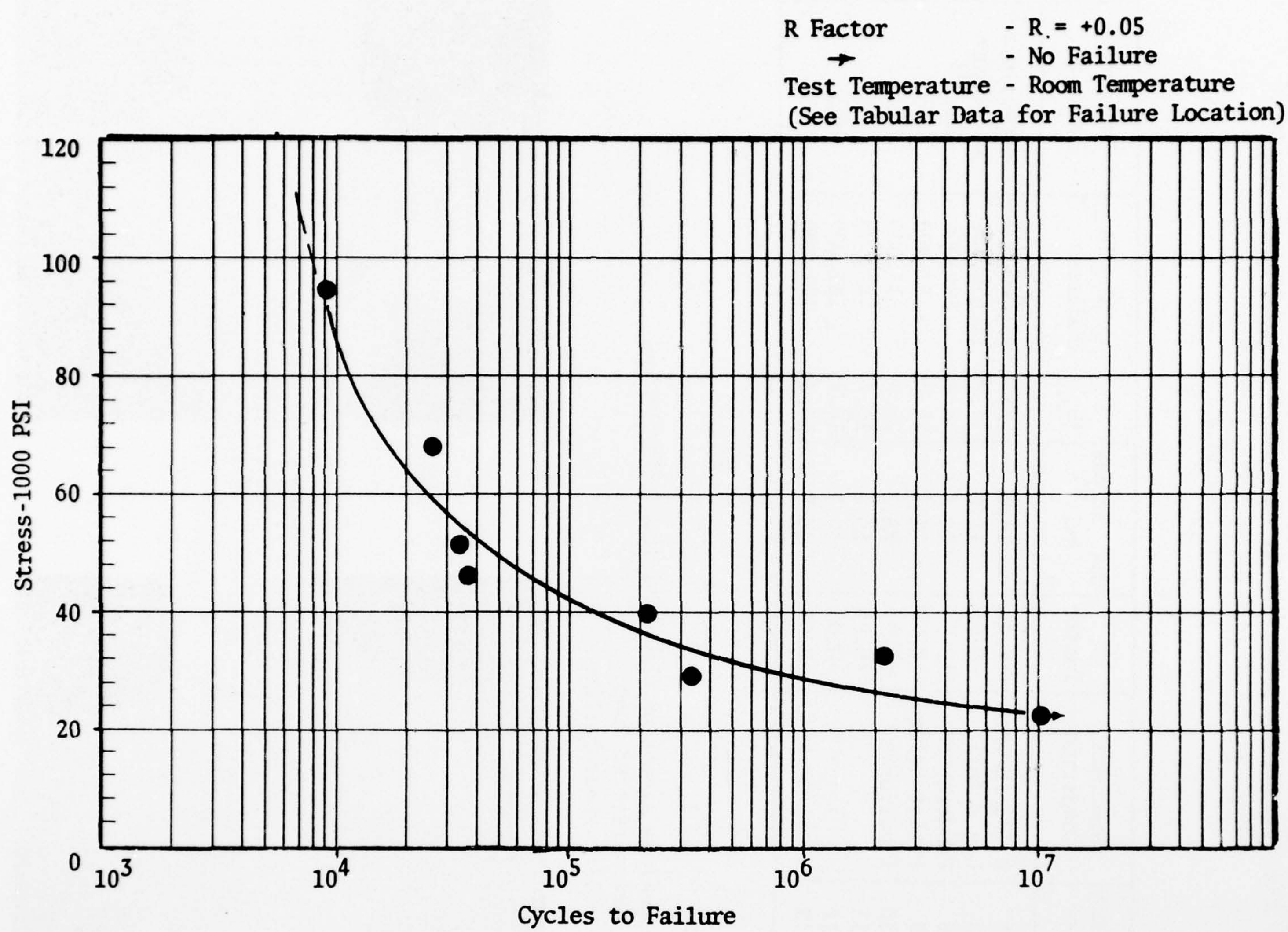


Figure 67. Axial Tension - Tension Fatigue Test Results for (0.375 In. Nominal Leg) Full Penetration Fillet Welded Cruciforms Fabricated From AF1410 Alloy Steel (Symmetrical Joint) WS Series

Table 44

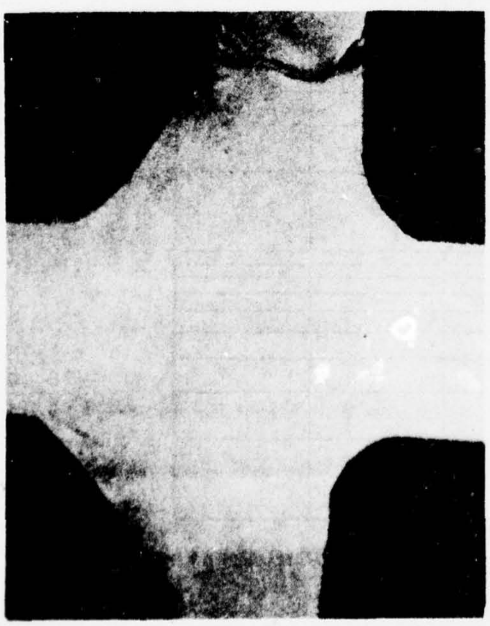
ROOM TEMPERATURE AXIAL FATIGUE TEST RESULTS FOR FULL PENETRATION FILLET-WELDED AF1410 ALLOY STEEL (ASYMMETRICAL JOINT)

$F_{tu} = 254.4$

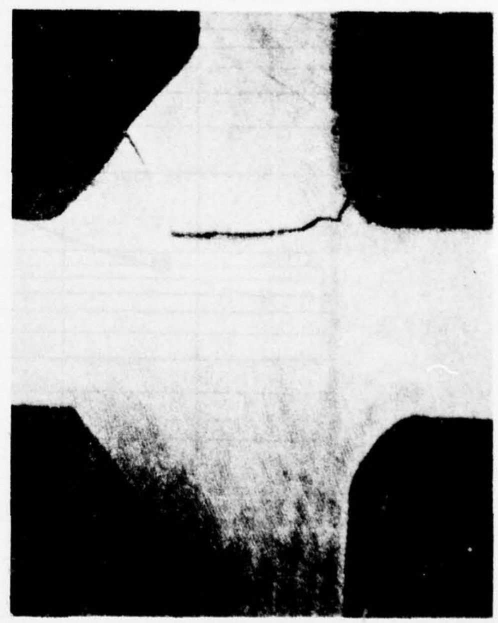
Specimen Ident	Specimen Condition	R Factor	Max. Stress ksi (1)	% F_{tu}	Cycles To Failure	Failure Location
WA-6	0.375 in. nom	+0.05	18.0	7.1	23,249,000	No Failure
WA-7	Leg - full	+0.05	12.6	4.9	11,635,000	No Failure
WA-8	Penetration	+0.05	20.4	8.0	426,000	HAZ (2)
WA-9	Fillet-welded	+0.05	29.5	11.6	232,000	HAZ
WA-10	Cruciforms	+0.05	75.2	29.6	17,000	HAZ
WA-11		+0.05	50.2	19.7	67,000	(3)
WA-12		+0.05	37.7	14.8	181,000	HAZ
WA-13		+0.05	45.3	17.8	121,000	HAZ

NOTES:

(1) Maximum stress on the axial load carrying leg
(2) Heat-affected zone
(3) Fillet shear failure



WA-8



WA-11

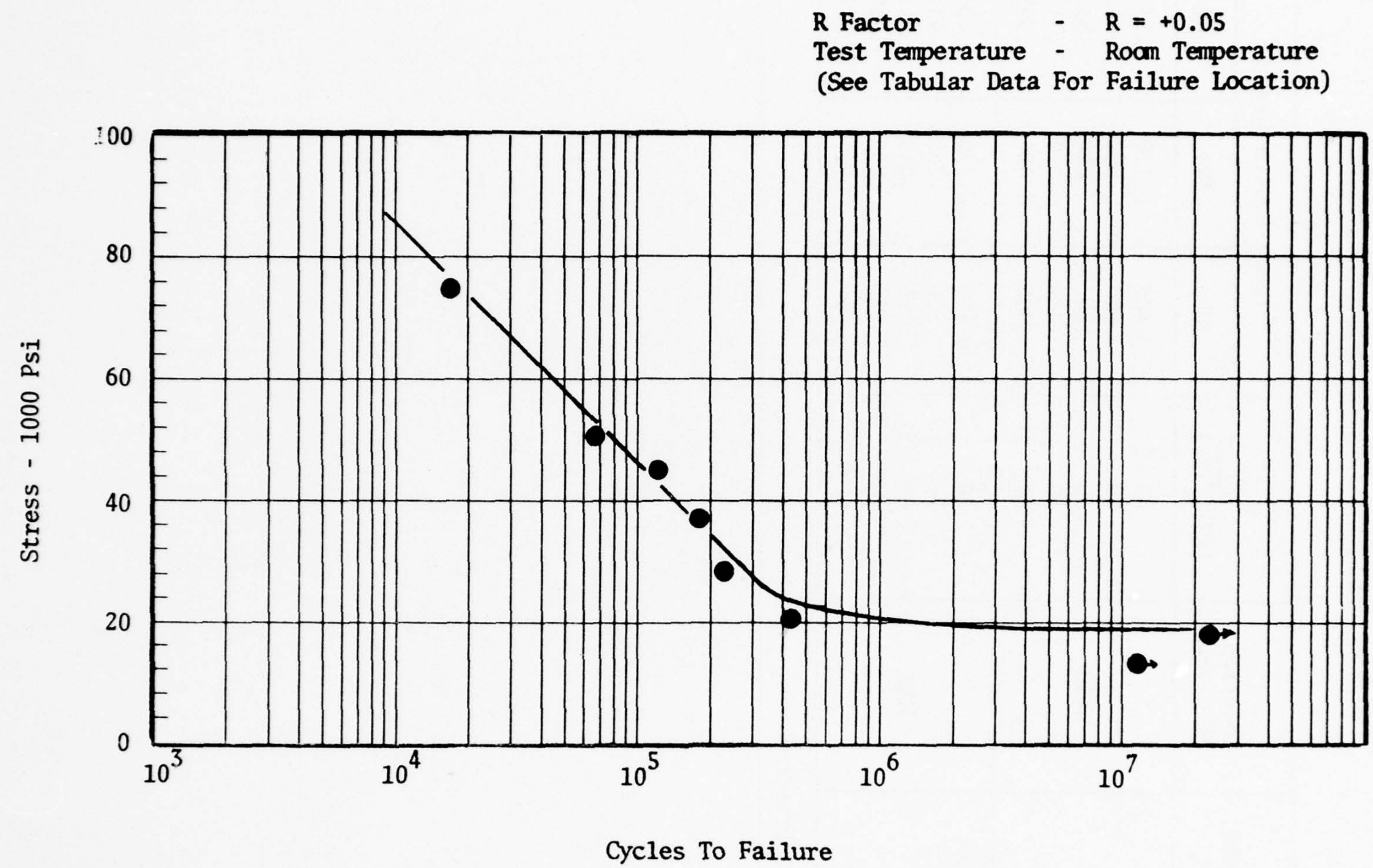


Figure 68 . Axial Tension - Tension Fatigue Test Results for (0.375 In. Nominal Leg) Full Penetration Fillet Welded Cruciforms Fabricated From AF1410 Alloy Steel (Asymmetrical Joint) WA Series

Table 45

STRESS CORROSION IN 3-1/2-PERCENT NaCl

Specimen No.	Location of Crack	K_{IC} (KSI $\sqrt{in.}$)	Crack Growth (hours)		
			50	100	500
S1	Weld	60	0.100	0.110	0.135
S5		50	.000	.000	.010
S4		40	.000	.000	.010
S2		40	.005	.010	.015
S3		30	.005	.005	.005
S10*	HAZ	80	0.130	0.170	0.200
S9		70	.200	.260	.440
S6		60	.010	.010	.010
S7		40	.030	.060	.140
S8		30	.010	.010	.010

*Crack branched

The weld specimens displayed a greater resistance to stress corrosion cracking than the HAZ. Based on these data, one would not expect significant stress corrosion cracking to occur in weld metal at stress intensities less than 60 ksi $\sqrt{\text{in.}}$ In the HAZ, scatter in the results makes a quantitative assessment difficult. Growth occurred at K_{Ic} of 40, but essentially none occurred at 60 (compare specimen S6 and S7). However, in comparing these HAZ results with those obtained for the parent metal, it is apparent that no degrading of parent metal stress corrosion resistance occurred in the heat-affected zone of the weld.

Fatigue Crack Growth Rate (da/dN)

The da/dN curves derived for the welded specimens in the fusion zone are shown in figures 69 and 70 for tests in air. The crack growth rate in the weld deposit is slower than that observed for the parent metal da/dN tests. One weld-zone specimen was tested in 3-1/2 percent NaCl; the da/dN curve is shown in figure 71 . Comparing this curve with those obtained in air, there does not appear to be an effect of the 3-1/2 percent NaCl environment on the crack growth rate of the weld deposit.

Experimental difficulties were encounted with the attempt to derive fatigue crack growth rate data for the heat-affected zone (HAZ) of the welds. Three specimens were tested. The first resulted in the crack wandering out of plane as shown in figure 72. In an attempt to drive the crack straight, the second specimen was grooved on both faces along the desired crack-growth path in an attempt to force the crack to grow in-plane. However, when the specimen was tested the crack climbed out of the groove, and the data from this specimen were not usable.

In a further effort to correct this experimental problem, the height/width ratio was changed from 0.486 (the standard ratio used for all the configurations shown in the specimen drawing) to 0.600 by cutting 1.180 inches off the end of the specimen. This revised specimen was the configuration used to successfully obtain da/dN data for the fusion zone. The last remaining HAZ specimen was modified to the 0.600 H/W ratio and tested. The crack again grew off-plane as shown in figure 73 ; no improvement was achieved in controlling the crack growth direction of the HAZ by increasing the H/W ratio.

The tabular data for the da/dN tests on the weld specimens are contained in appendix D.

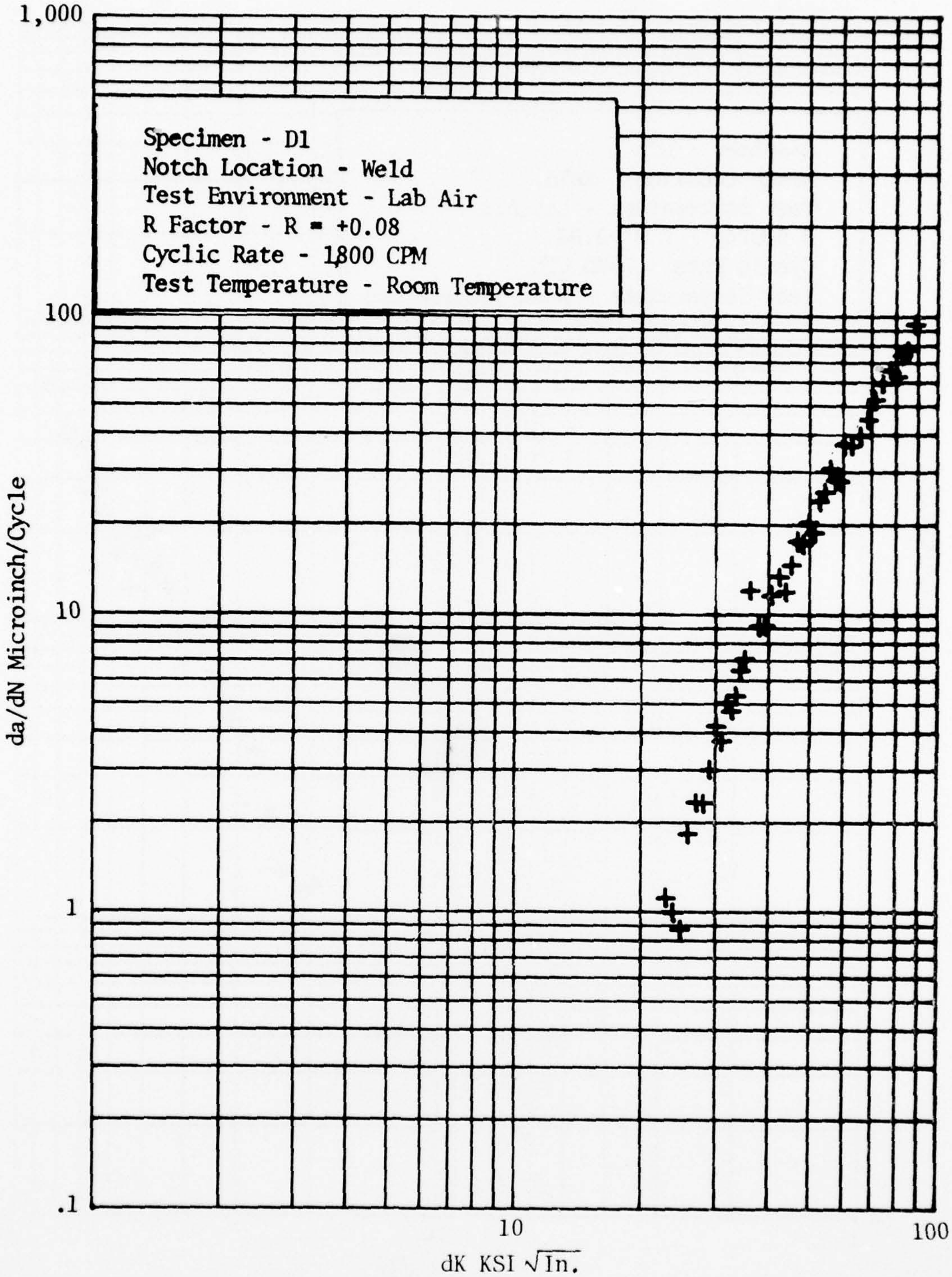


Figure 69 . Weld da/dN, Air

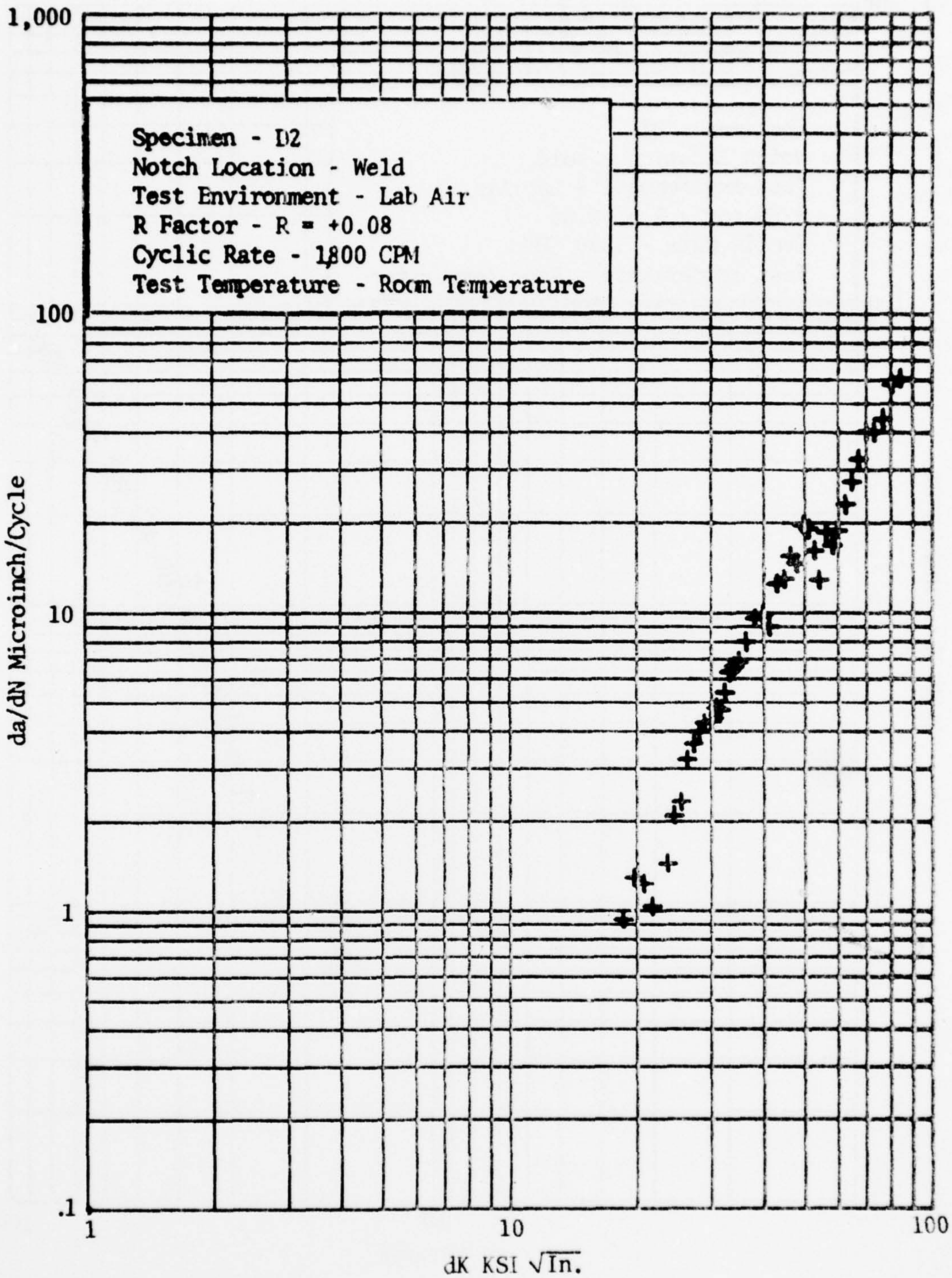


Figure 70 . Weld da/dN, Air

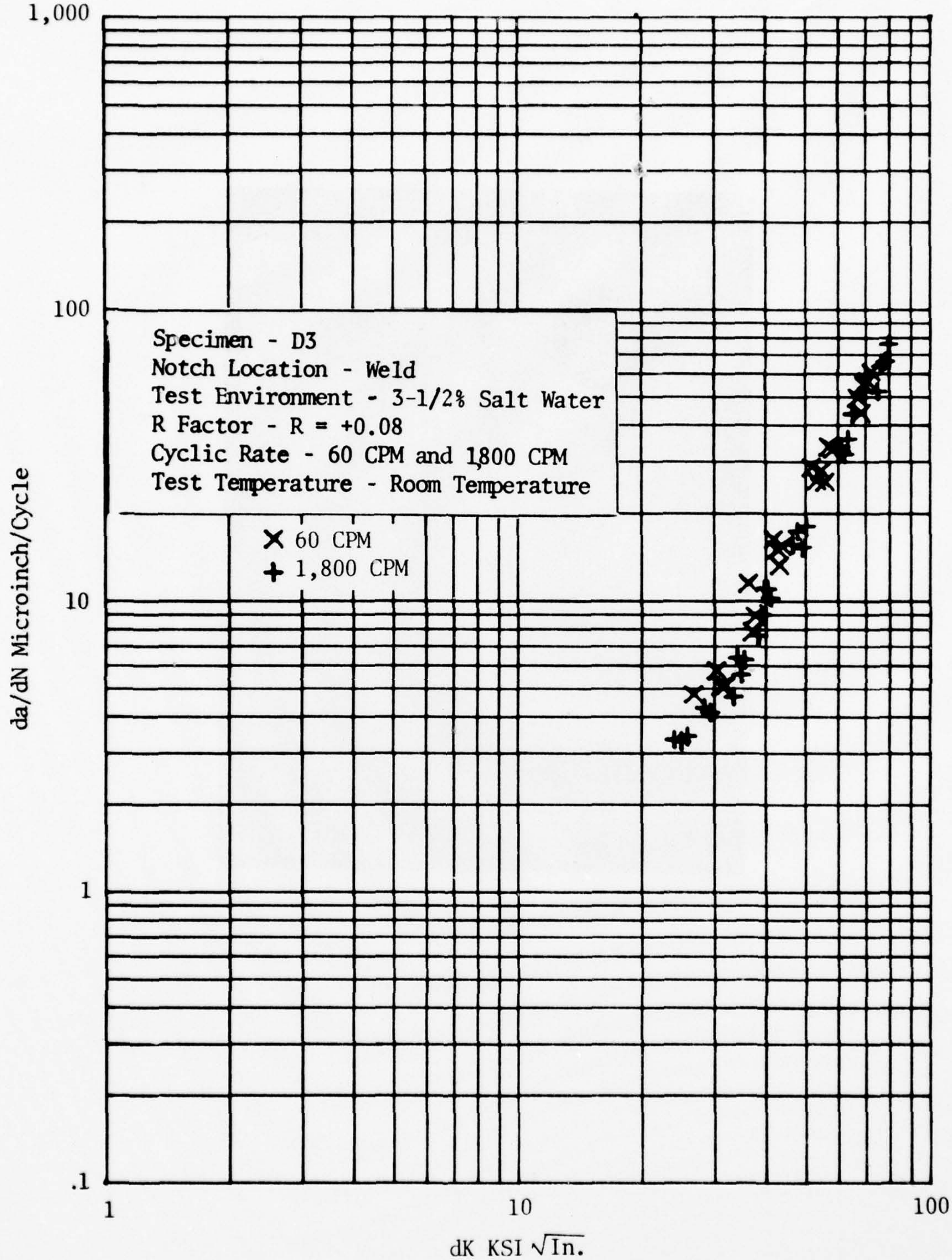


Figure 71 Weld da/dN, 3 1/2-Percent NaCl

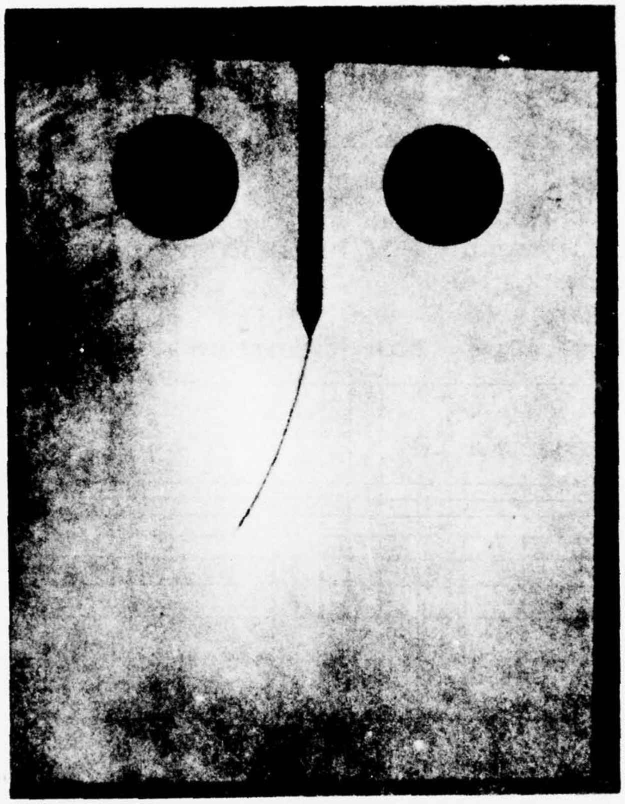


Figure 72. Crack Path Typical of HAZ Fatigue Crack Growth Specimens

MATERIAL PROPERTIES SUMMARY

Static and dynamic mechanical properties, fatigue crack growth rates, and stress corrosion resistance was determined for AF1410 parent metal and weldments. All properties measured exhibited isotropic behavior and met the mechanical property goals established for the alloy.

Exceptionally high bearing strength, nearly twice the tensile ultimate, was observed. Kic of the parent metal averaged 138 KSI $\sqrt{in.}$ at 70 degrees, and showed a 20 percent drop at -65° F. Fatigue crack growth rates were independent of rolling direction, and showed little effect of a 3-1/2 percent NaCl environment. The stress corrosion resistance of the parent metal was shown to be approximately 60 KSI $\sqrt{in.}$ in simulated sump tank water and 30 KSI $\sqrt{in.}$ in 3-1/2 percent NaCl. AF1410 does not desplay a marked sensitivity to hydrogen embrittlement.

Welding was accomplished in a production weld shop without difficulty and with good welder acceptance. Butt welds possessed uniform tensile properties, and intentional repairs did not show a marked effect on the properties. Some root cracking occurred in the corner penetration fillet welds, which is not uncommon on this type of weld. No difficulties were encountered in the full penetration welds, and tensile properties of these specimens were very consistent. The fracture toughness of the weld and HAZ was slightly higher than the parent metal, even with a single repair weld. The toughness loss at -65° F is not as high as that measured on the parent metal.

Fatigue of the butt welds resulted in a predominant subsurface failure origin at a small, discrete discontinuity when the reinforcement was removed prior to testing. The fatigue strength of the butt welds is significantly lower than that of the parent metal. The fatigue strength of both the partial- and full-penetration fillet welds was low, with the partial-penetration fillet weld only slightly inferior to the full-penetration fillet weld.

The stress corrosion resistance of the weld deposit in 3-1/2 percent NaCl was approximately 60 KSI $\sqrt{in.}$, twice that observed for the parent metal. The HAZ stress corrosion resistance was not degraded below that of the parent metal.

The fatigue crack growth rate of the weld deposit is slower than that of the parent metal, and no effect of a 3-1/2 percent NaCl environment was detected. The growth rate in the HAZ could not be measured, as no means was found to force the crack to grow on a plane.

FRACTURE MECHANICS ANALYSIS VERIFICATION TESTS

A series of 32 fracture mechanics analysis verification tests were conducted as part of the phase II materials test program. The purpose of this type of testing was to generate crack-growth data from flaw configurations typical of those which develop in aircraft structure, with the intent of using this data to support and verify the development of analytical prediction methodology in AF1410 steel. The specimen configurations shown in figure 73 were tested to either a constant amplitude cyclic load or to a generalized spectrum of loads simulating the loading of an element in a lower wing skin. A listing of the parameters pertinent to each of the tests is shown in table 46. The two variations of the test spectrum are shown in tables 47 and 48, one spectrum having three steps with compression loads, and the other entirely without compression.

ANALYTICAL METHODOLOGY

The initial analytical predictions of the test coupon crack-growth curves were made using da/dN vs ΔK crack-growth rate properties generated from compact-tension type specimens of AF1410 steel from the material properties program. Conventional fracture mechanics stress intensity formulae together with appropriate surface, width, and stress gradient factors were used in predicting the growth curves of the test cracks. A comparison of these initial predictions and the actual test growth curves were made, and the level of empirical correction factors required to provide reasonable agreement between test and analysis was determined.

The Rockwell B-1-developed computer program "EFFGRO, Crack Propagation Analysis by the Vroman Model" was used for the growth rate predictions. EFFGRO utilizes a specialized integration routine where an initial crack size, a_i, is chosen, and the crack-growth rate, da/dN, is integrated to yield the relationship between a and N for the given stress spectrum. When applicable, the influence of stresses in the compression region on crack-growth rate is taken into consideration.

The fatigue crack-growth rate equation used in EFFGRO is the following Paris-type equation with the addition of Walker's stress ratio correction index, m, and the exponent, q, which accounts for the influence of compression stresses on crack growth.

Table 46

SPECIMEN LIST - FRACTURE MECHANICS ANALYSIS VERIFICATION TESTS

TEST NO.	PART NO.	CONFIGURATION	TYPE LOAD	ENVIRON.	MAX STRESS
11	3109-100004-11	Part-Thru Crack	Const. Amplit	Lab Air	75 KSI
12		Part-Thru Crack	Const. Amplit	Lab Air	150 KSI
13		Part-Thru Crack	Const. Amplit	Sump Water	75 KSI
14		Part-Thru Crack	Const. Amplit	Sump Water	150 KSI
15		Part-Thru Crack	Spectrum	Lab Air	120 KSI
16		Part-Thru Crack	Spectrum	Lab Air	150 KSI
17		Part-Thru Crack	Spectrum	Sump Water	120 KSI
18	3109-100004-11	Part-Thru Crack	Const. Amplit	Lab Air	150/-75KSI
21	3109-100004-23	Cracked Hole	Const. Amplit	Lab Air	100 KSI
22	3109-100004-21	Cracked Hole	Const. Amplit	Lab Air	100 KSI
23	3109-100004-21	Cracked Hole	Const. Amplit	Lab Air	±100 KSI
24	3109-100004-21	Cracked Hole	Const. Amplit	Sump Water	100 KSI
25	3109-100004-23	Cracked Hole	Spectrum	Lab Air	100 KSI
26	3109-100004-21	Cracked Hole	Spectrum	Lab Air	100 KSI
27	3109-100004-21	Cracked Hole	Spectrum	Lab Air	125 KSI
28	3109-100004-21	Cracked Hole	Spectrum	Sump Water	100 KSI
29	3109-100004-21	Cracked Hole	Const. Amplit	Lab Air	100/-50KSI
30	3109-100004-21	Cracked Hole	Spectrum	Lab Air	125 KSI
31	3109-100004-31	Through Crack	Const. Amplit	Lab Air	100 KSI
32		Through Crack	Const. Amplit	Lab Air	±100 KSI
33		Through Crack	Const. Amplit	Sump Water	100 KSI
34		Through Crack	Spectrum	Lab Air	100 KSI
35		Through Crack	Spectrum	Lab Air	75 KSI
36		Through Crack	Spectrum	Sump Water	100 KSI
37		Through Crack	Const. Amplit	Lab Air	100/-50KSI
38	3109-100004-31	Through Crack	Spectrum	Lab Air	75 KSI
41	3109-100005-1	Cracked Hole	Const. Amplit	Lab Air	100 KSI
42		Cracked Hole	Const. Amplit	Lab Air	120 KSI
43		Cracked Hole	Spectrum	Lab Air	100 KSI
44		Cracked Hole	Spectrum	Lab Air	80 KSI
45	3109-100005-1	Cracked Hole	Const. Amplit	Lab Air	80 KSI

NOTE: Spectrum tests 30, 38, 43, & 44 did not have compression stresses; all other spectrum tests had compression stresses equal to 15% of the maximum tension stress.

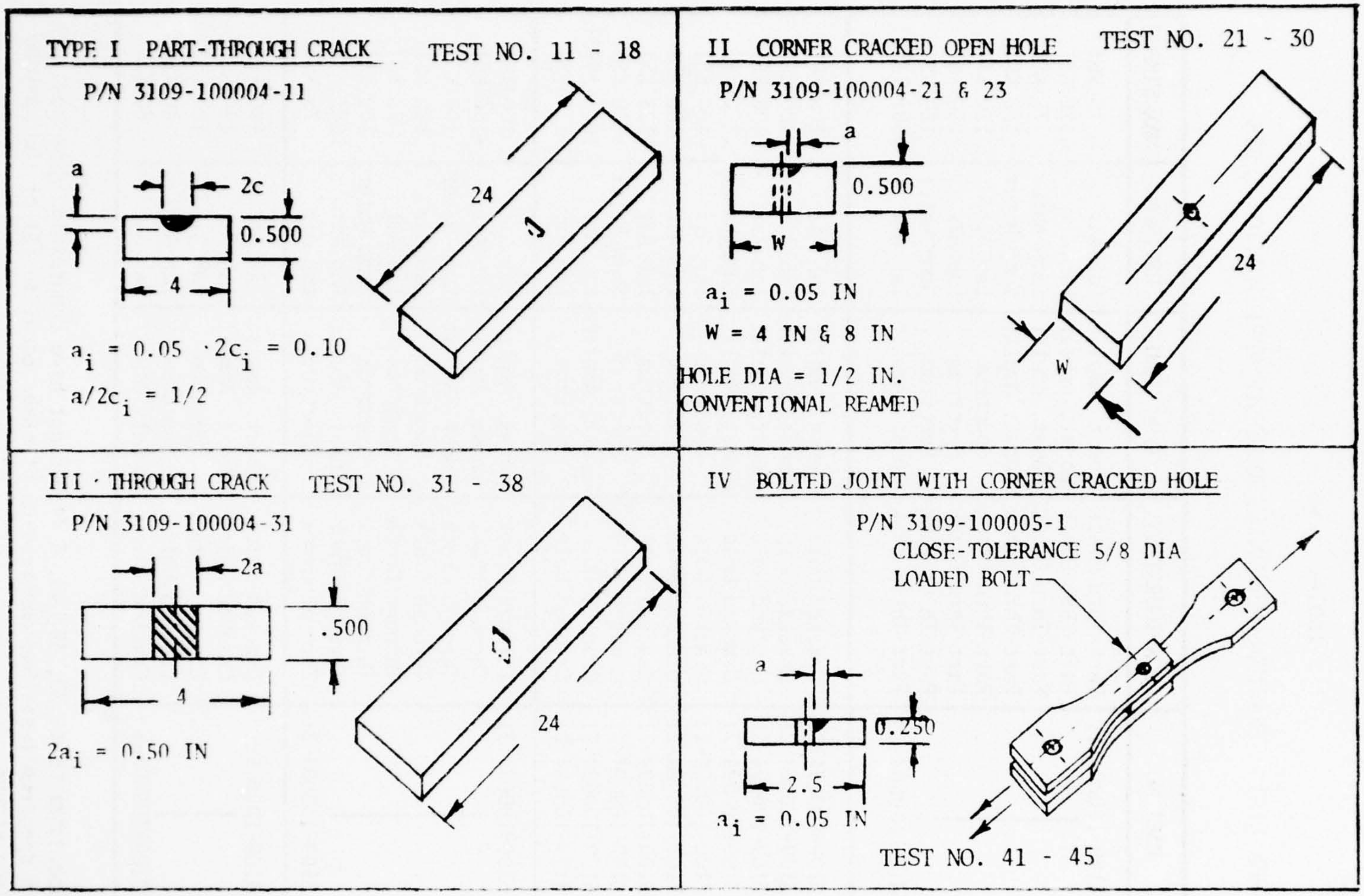


Figure 73. Fracture Mechanics Analysis Verification Test Program Test Specimen Configurations

Table 47

SPECTRUM FOR FRACTURE MECHANICS ANALYSIS VERIFICATION TESTS WITH COMPRESSION

This Spectrum Used for Test No. 15-17, 25-28, and 34-36

STEP	SEGMENT	RANGE IN % MAX LOAD		CYCLES/MISSION
		MAX LOAD	MIN LOAD	
1	GROUND	-3%	-15%	1
2	POST TAKE-OFF	100	58	1 Every 100 Missions
3		90	58	1 Every 10
4		68	58	1
5		58	45	1
6		69	65	1
7		70	40	1
8		56	49	3
9	CLIMB CRUISE & REFUEL	51	24	1
10		63	51	2
11		51	43	1
12		69	36	1
13		36	13	1
14		48	36	6
15		36	30	1
16	FLY-UP	76	31	1
17		53	32	1
18	TERRAIN FOLLOWING	71	55	1 Every 10
19		62	33	1
20		51	40	7
21		55	13	1
22		38	23	48
23		34	0	1
24		24	13	35
25		72	8	1
26		56	11	9
27		38	19	10
28	PRE-LANDING	99	53	1 Every 100
29		88	-12	1 Every 10
30		75	53	1
31	GROUND	-3	-15	1
32	TAKE-OFF	85	56	1
33	CLIMB	88	51	1
34	PRE-LANDING	53	33	1
35		62	53	19
36		53	46	2
37		81	48	1
38		69	58	1
39		70	32	1
40		45	40	9
41		59	43	5
42		55%	46%	29
				Total 208.32

AD-A046 705 ROCKWELL INTERNATIONAL LOS ANGELES CALIF LOS ANGELE--ETC F/G 1/3
LOWER COST BY SUBSTITUTING STEEL FOR TITANIUM. AF1410 STEEL-DET--ETC(U)
JUN 77 W E ROUTH F33615-75-C-3109
UNCLASSIFIED RI/LAAD-NA-77-217 AFFDL-TR-77-73 NL

3 OF 4
AD A046705

Table 48

SPECTRUM FOR FRACTURE MECHANICS ANALYSIS VERIFICATI

This Spectrum Used for Test No. 30,38,43

STEP	SEGMENT	RANGE IN % MAX LOAD	
		MAX LOAD	MIN LOAD
1	GROUND	0	0
2	POST TAKE-OFF	100	58
3		90	58
4		68	58
5		58	45
6		69	65
7		70	40
8		56	49
9	CLIMB CRUISE & REFUEL	51	24
10		63	51
11		51	43
12		69	36
13		36	13
14		48	36
15		36	30
16	FLY-UP	76	31
17		53	32
18	TERRAIN FOLLOWING	71	55
19		62	33
20		51	40
21		55	13
22		38	23
23		34	0
24		24	13
25		72	8
26		56	11
27		38	19
28	PRE-LANDING	99	53
29		88	0
30		75	53
31	GROUND	0	0
32	TAKE-OFF	85	56
33	CLIMB	88	51
34	PRE-LANDING	53	33
35		62	53
36		53	46
37		81	48
38		69	58
39		70	32
40		45	40
41		59	43
42		55%	46%

When R, the stress ratio, ≥ 0 $$\frac{da}{dN} = C \left[\frac{\Delta K}{(1-R)^{1-m}}\right]^n$$

and when R<0, $$\frac{da}{dN} = C \left[(1-R)^q \quad K_{max}\right]^n$$

where C (the intercept), m, and n (the slope) are experimentally determined constants from tests at positive stress ratios, and q is determined from negative R tests, ΔK is the stress intensity factor range, and K_{max} is the maximum stress intensity value for a given cycle.

The factor, q, in the crack-growth equation controls the influence of the compression region of the load cycle. As can be seen from the slopes of the curves in figure 74, a corner-cracked hole is more susceptable to crack-life degradation for deeper excursions into compression than the part-through or through-cracks. This is caused by the concentration of stresses in the field adjacent to the hole. Accordingly, a progressively higher value of q is required to predict the shorter crack lives for the compression-loaded constant amplitude tests of the hole specimens.

The relatively low factors of q assigned to the spectrum tests reflect the low level and infrequent occurrences of compression stresses in the test spectrum. For a spectrum with frequent and significant stress reversals the higher values of q, as determined from the constant amplitude tests, would be appropriate. Such higher values were used in the final analysis of the Wing Sweep Actuator Inboard Attach Fitting since that spectrum has frequent and significant load reversals.

The following listed sets of equation coefficients, including the adjusted C values, together with the listed schedule of q values for the compression tests, were used for the analytical predictions plotted on each of the test curves shown in appendix E, figures E-1 through E-29.

Laboratory Air Tests	Sump Tank Water Tests
$C = 7.5 \times 10^{-18}$	$C = 8.5 \times 10^{-18}$
$m = 0.395$	$m = 0.395$
$n = 2.65$	$n = 2.65$

Schedule of q	Constant Amplitude			Spectrum
	R = 0	R = -0.5	R = -1	
Part-Through Crack	0	0.20	0.30	0.10
Corner Cracked Hole	0	0.40	0.60	0.20
Through-Crack	0	0.15	0.20	0.10

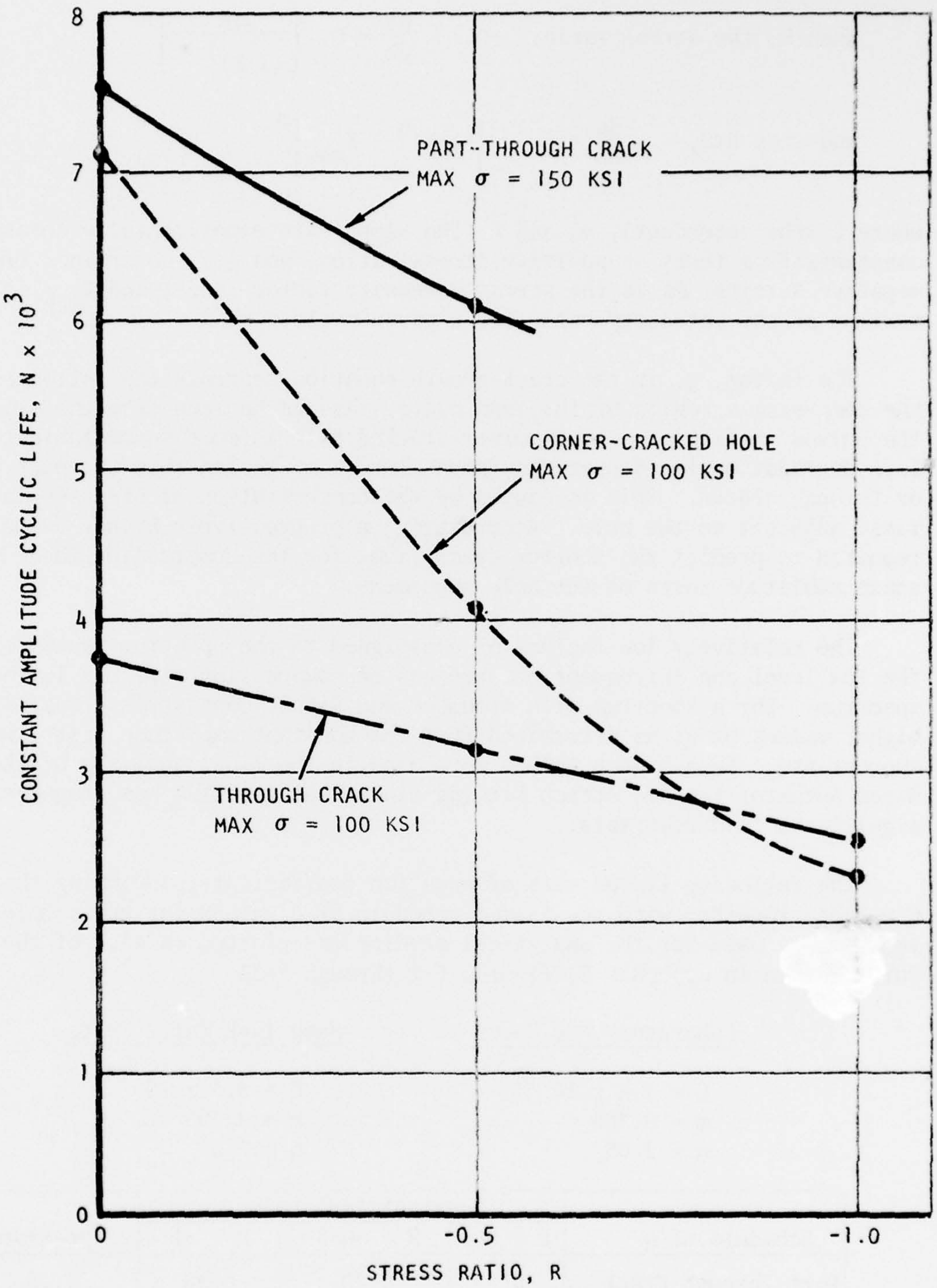


Figure 74 Cyclic Life Versus Stress Ratio for Constant Amplitude Crack-Growth Tests

CORRELATION WITH PREDICTIONS

Very good agreement is shown for the part-through and corner-cracked hole groups. Agreement is not as good for the through-crack series but is acceptable for state-of-the-art crack prediction methodology. The predictions are conservative to the extent that test lives exceeded those predicted. Obviously, it would have been possible to tailor the coefficients to predict each individual test exactly, but to do this would require a different set of crack-growth equation coefficients for each test. However, the intent of this study was to determine a universal set of values that would provide a reasonable prediction for all tests. It is felt that this has been accomplished.

Predictions are not shown for the bolted joint tests since the lives of these tests are greatly impacted by the clamping action of the torqued bolt. The actual test lives of spectrum tests 43 and 44 are approximately six times the life that would be predicted if these loads were applied to open-hole specimens, and the life of constant amplitude test number 45 is approximately two times that of an open-hole test. The greater difference in test and predicted lives exists for the spectrum tests since the lower level spectrum loads are effectively prevented from reaching the crack front by the clamping action of the bolt torque and only the higher loads cause crack extension, whereas, in the analysis, all loads are assumed fully effective on the crack. The magnitude of the constant amplitude loads is such that they are effective to a larger degree in test.

Section VII

MACHINABILITY/HEATTREAT TEST

INTRODUCTION

A total of 54 specimens were given various combinations of pre- and postmachining heat treatments and then tested to determine tensile and Charpy impact values. The test results were used to evaluate the effect of the premachining heat treatments (selected in phase I) on the response of various subsequent postmachining heat treatments. On the basis of this evaluation, a final combination of pre- and postmachining heat treatments has been tentatively selected.

Refinement of the postmachining aging temperature is now under development, after which the effect of the selected heat treatments on weldments will be evaluated.

PROCEDURES

A total of 55 AF1410 steel blocks were machined to a size of 1 by 2 by 6 inches from as-received stock that had been final rolled and air-cooled from 1,570° F. Twenty-seven of these blocks were then subjected to the type F and 27 to the type H premachining heat treatments selected in phase I (No. 1 and 2 of table 49). Of the 27 blocks in each group, 10 were postmachine heat-treated with air cooling, 10 with oil quenching, and seven with water quenching from austentizing temperatures of 1,450°, 1,500°, 1,550°, 1,600°, and 1,650° F. Selected blocks were cooled to -100° F to promote additional transformation of austenite to martensite. All of the blocks were aged at 950° F for 5 hours. The postmachining heat treatments used are summarized in table 49 and figure 75. The 55th block was given the standard AF1410 heat treatment (No. 4 of table 49) without being subjected to the premachining heat treatment for comparison purposes.

Each heattreated block was machined and sectioned to obtain three round tensile specimens and three standard Charpy impact specimens (figure 76). The specimens were machined and tested in accordance with ASTM E-8 and ASTM E-23 for tensile and Charpy impact properties, respectively.

RESULTS

The tensile and Charpy impact results are presented in tables 50, 51, and 52 and in figures 77 through 89 as average values of three tests along with the standard deviations. These results correlate with the various heattreat combinations as described in the following paragraphs.

Table 49

AF 1410 HEAT TREATMENT PROCEDURES
USED IN PHASE II

No.	Type of Heat Treatment	Procedure
1	F premachining (per phase I)	1. Austenitize at 1,250° F for 8 hours 2. Air-cool
2	H premachining (per phase I)	1. Austenitize at 1,300° F for 4 hours 2. Air-cool 3. Age at 850° F for 24 hours
3	Postmachining	1. Austenitize at 1,650° F for 1 hour 2. Air-cool 3. Austenitize for 1 hour at either 1,450°, 1,500°, 1,550°, 1,600° or 1,650° F 4. Either: a. Air cool b. Oil quench c. Water quench 5. Either: a. No refrigerated cooling b. Cool to -100° F 6. Age 950° F for 5 hours 7. Air-cool
4	Standard	1. Austenitize at 1,650° F for 1 hour 2. Water quench 3. Austenitize at 1,500° F for 1 hour 4. Water quench 5. Age at 950° F for 5 hours 6. Air cool

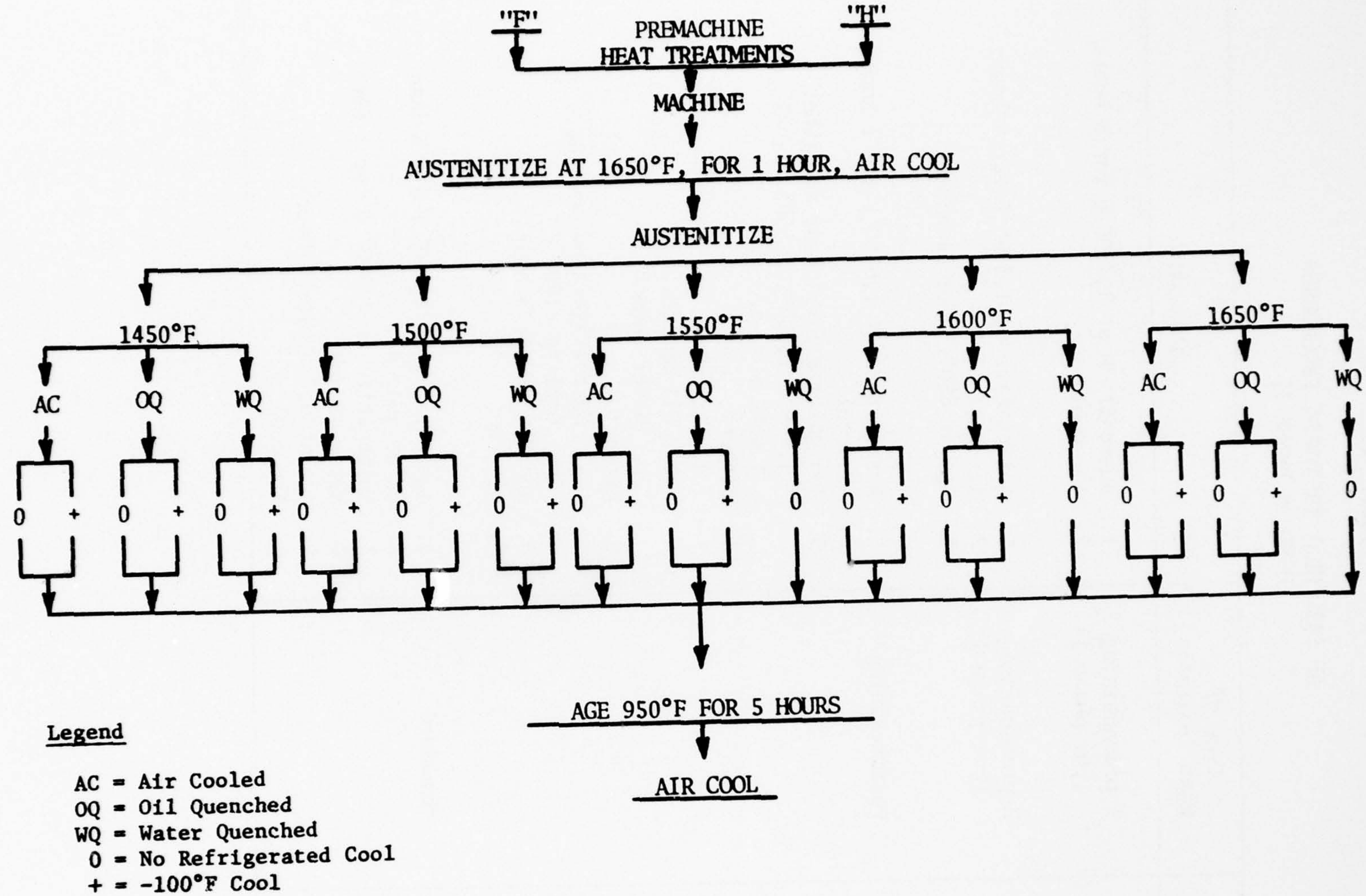


Figure 75 . Flow Chart Showing the Various Heat Treatment Sequences Tested

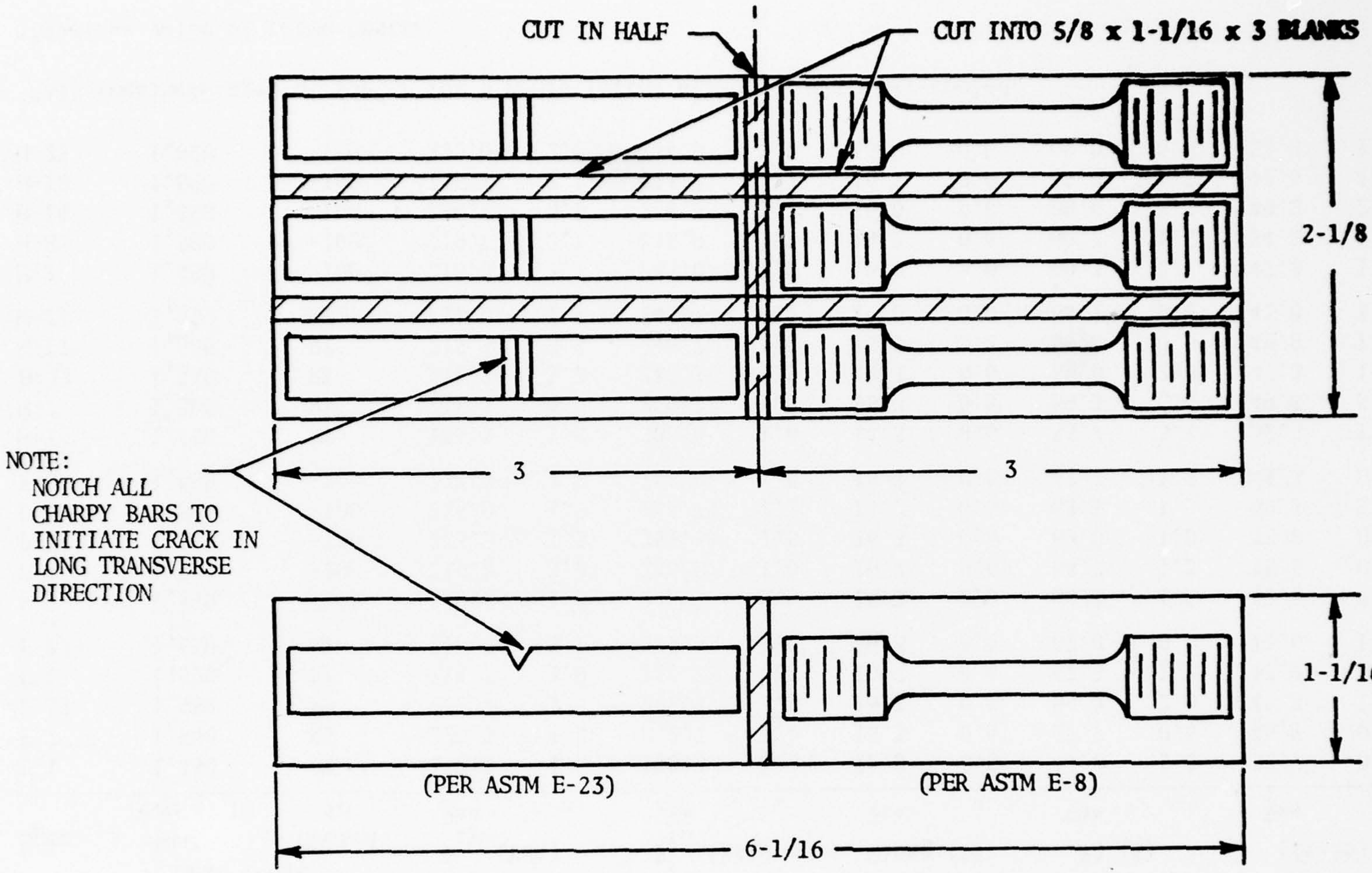


Figure 76 Sectioning and Machining of AF1410 Specimens for Mechanical Testing

Table 50

ME[illegible]AL PROPERTIES OF AF 1410
SPECIM[illegible] TREATED WITH AIR COOLING*

Spec	Heat Treat Aust Temp (° F)	Heat Treat Cooled To	F_{ty} (ksi) $\overline{X}$**	F_{ty} (ksi) σ	F_{tu} (ksi) $\overline{X}$**	F_{tu} (ksi) σ	Elong (%) $\overline{X}$**	Elong (%) σ	RA (%) $\overline{X}$**	RA (%) σ	CHARPY (ft-lb) $\overline{X}$**	CHARPY (ft-lb) σ
F-1	1,450	RT	173.3	1.5	198.3	1.2	16.0	0.0	47.0	5.2	32.7	0.8
F-7	1,500	RT	220.3	1.5	252.7	1.2	15.3	0.6	67.7	0.6	46.8	0.9
F-13	1,550	RT	216.7	1.2	245.3	1.5	16.3	0.6	69.0	2.0	47.3	1.7
F-17	1,600	RT	214.7	2.9	250.7	0.6	16.7	0.6	67.3	1.2	47.0	1.0
F-22	1,650	RT	210.7	3.1	243.3	1.6	16.3	0.6	67.0	0.0	41.0	1.0
F-2	1,450	-100	220.7	1.5	243.7	0.6	16.7	0.6	66.3	1.5	42.8	0.7
F-8	1,500	-100	219.0	3.0	246.0	1.0	16.7	0.6	68.7	1.2	45.5	0.5
F-14	1,550	-100	223.3	1.5	251.3	1.5	16.3	0.6	69.0	1.0	47.8	0.9
F-18	1,600	-100	215.0	1.7	245.7	1.2	15.7	0.6	68.3	1.2	49.3	5.3
F-23	1,650	-100	214.7	1.5	245.0	1.0	15.3	0.6	67.7	1.2	41.3	0.7
H-1	1,450	RT	185.3	1.8	208.0	1.0	14.3	0.6	55.7	3.2	32.5	1.0
H-7	1,500	RT	216.3	4.6	250.7	1.2	15.7	0.6	69.3	0.6	49.8	5.4
H-13	1,550	RT	216.7	1.2	245.3	1.5	16.3	0.6	69.0	2.0	47.3	1.7
H-17	1,600	RT	215.3	3.5	246.7	1.5	15.7	1.2	69.0	0.0	49.9	1.7
H-22	1,650	RT	211.0	1.7	243.7	0.6	17.0	0.0	68.7	0.6	43.0	3.0
H-2	1,450	-100	216.0	2.7	243.0	1.0	16.0	0.0	69.3	2.1	47.8	1.8
H-8	1,500	-100	219.7	2.1	243.0	1.7	15.7	0.6	60.7	1.5	54.5	1.7
H-14	1,550	-100	220.7	3.2	248.3	1.2	16.0	0.0	68.0	2.0	49.2	2.2
H-18	1,600	-100	216.7	2.1	244.7	1.2	16.7	0.6	68.7	1.5	47.5	4.8
H-23	1,650	-100	212.0	2.0	244.3	1.5	16.7	0.6	69.0	0.0	52.5	2.6

*All specimens aged at 950° F for 5 hours (after air-cool) then air-cooled.

**Average value of three tests.

Table 51

MECHANICAL PROPERTIES OF AF 1410
SPECIMENS HEAT TREATED WITH OIL QUENCHING*

SPEC	HEAT TREAT		F_{ty} (ksi)		F_{tu} (ksi)		ELONG. (%)		R.A. (%)		CHARPY (ft-lb)	
NO.	AUST TEMP (° F)	COOLED TO	$\overline{X}$**	σ	$\overline{X}$**	σ	$\overline{X}$**	σ	$\overline{X}$**	σ	$\overline{X}$**	σ
F-3	1450	RT	176.0	1.0	199.0	0.0	15.0	0.0	52.3	1.6	34.0	0.5
F-9	1500	RT	221.0	3.5	252.3	1.3	16.0	0.0	69.0	1.0	44.0	1.7
F-15	1550	RT	220.7	2.6	249.3	1.2	15.7	0.7	69.0	1.0	44.7	3.8
F-19	1600	RT	220.0	2.6	247.7	2.2	16.0	0.0	69.3	0.8	41.8	9.5
F-24	1650	RT	219.7	2.1	247.7	2.0	15.0	0.0	68.3	0.8	48.5	2.2
F-4	1450	-100	224.7	1.9	243.7	2.2	15.0	1.0	68.0	0.0	41.5	1.0
F-10	1500	-100	229.3	4.3	251.7	1.7	16.0	0.0	69.0	1.0	44.2	0.3
F-16	1550	-100	225.3	2.5	242.0	1.0	16.0	0.0	69.0	0.0	45.0	1.5
F-20	1600	-100	226.0	3.6	246.3	2.4	15.7	0.7	69.0	0.0	43.2	1.5
F-25	1650	-100	218.7	1.6	248.3	1.2	15.7	0.7	67.3	1.3	44.8	4.5
H-6	1450	RT	176.0	1.0	192.3	1.2	17.7	0.6	61.0	1.7	41.5	3.0
H-9	1500	RT	223.0	2.6	242.0	1.0	17.7	0.6	69.0	0.0	48.5	0.9
H-15	1550	RT	220.0	1.0	246.0	1.7	16.3	1.2	69.3	0.6	51.0	0.9
H-19	1600	RT	219.7	3.1	249.0	2.6	16.7	0.6	60.7	1.5	49.8	1.4
H-24	1650	RT	218.7	2.1	248.3	2.1	15.7	0.6	68.0	1.0	45.8	2.6
H-4	1450	-100	226.3	3.1	244.7	2.1	15.0	0.0	69.7	0.6	47.2	1.0
H-10	1500	-100	225.7	0.6	246.3	0.6	16.0	1.0	68.7	0.6	48.8	3.8
H-16	1550	-100	223.0	2.6	248.3	2.1	15.7	0.6	69.7	0.6	52.7	2.2
H-20	1600	-100	223.3	2.5	247.3	0.6	16.7	0.6	68.3	0.6	44.3	1.1
H-25	1650	-100	223.5	3.5	247.7	1.5	15.7	0.6	68.7	0.6	47.2	2.0

*All specimens aged at 950° F for 5 hours (after oil quench) then air-cooled.

**Average Value of 3 Tests

Table 52

MECHANICAL PROPERTIES OF AF 1410
SPECIMENS HEAT TREATED WITH WATER QUENCHING*

SPEC NO.	HEAT TREAT AUST TEMP (° F)	HEAT TREAT COOLED TO	F_{ty} (ksi) $\bar{X}$**	F_{ty} (ksi) σ	F_{tu} (ksi) $\bar{X}$**	F_{tu} (ksi) σ	ELONG (%) $\bar{X}$**	ELONG (%) σ	RA (%) $\bar{X}$**	RA (%) σ	CHARPY (ft-lb) $\bar{X}$**	CHARPY (ft-lb) σ
F-6	1450	RT	177.0	1.0	192.7	1.5	15.0	0.0	58.0	2.6	38.7	2.5
F-11	1500	RT	222.7	2.1	240.7	1.6	16.0	0.0	70.3	0.8	49.2	2.3
F-27	1550	RT	226.7	2.1	248.0	1.0	15.3	0.6	69.0	1.0	44.5	3.0
F-21	1600	RT	223.7	1.9	243.3	1.6	15.7	0.7	69.7	1.0	48.2	2.0
F-26	1650	RT	220.5	2.1	241.7	1.7	15.7	0.7	68.7	1.0	46.5	0.5
F-5	1450	-100	225.7	1.6	237.0	2.6	15.0	0.0	69.3	0.8	43.7	1.2
F-12	1500	-100	228.3	1.6	242.7	2.6	15.0	0.0	70.0	0.0	54.7	3.3
H-3	1450	RT	184.0	1.0	205.0	1.7	14.3	0.6	56.3	2.1	33.7	1.6
H-11	1500	RT	225.3	1.5	243.3	2.1	15.0	0.0	69.0	1.0	50.3	4.0
H-27	1550	RT	222.0	1.0	245.0	1.7	16.0	0.0	68.7	0.6	55.2	1.0
H-21	1600	RT	221.0	1.7	242.0	2.6	17.3	0.6	70.3	0.6	60.8	3.1
H-26	1650	RT	222.0	1.7	243.3	4.9	17.7	0.6	69.7	1.5	52.7	2.0
H-5	1450	-100	226.0	2.6	240.0	2.6	15.0	0.0	70.7	0.6	51.0	1.8
H-12	1500	-100	230.7	2.3	248.7	3.1	16.0	0.0	69.0	1.0	53.8	0.9
PM + STD	1500	RT	228.0	1.7	247.7	0.6	15.3	0.6	70.7	1.2	60.0	4.4
F + STD	1500	RT	227.0	0.0	250.3	1.2	16.0	0.0	69.0	1.0	48.0	1.7
H + STD	1500	RT	227.7	0.6	251.0	1.7	16.3	0.6	68.3	1.2	46.5	0.5

*All specimens aged at 950° F for 5 hours (after water quench) then air-cooled.

**Average Value of 3 Tests

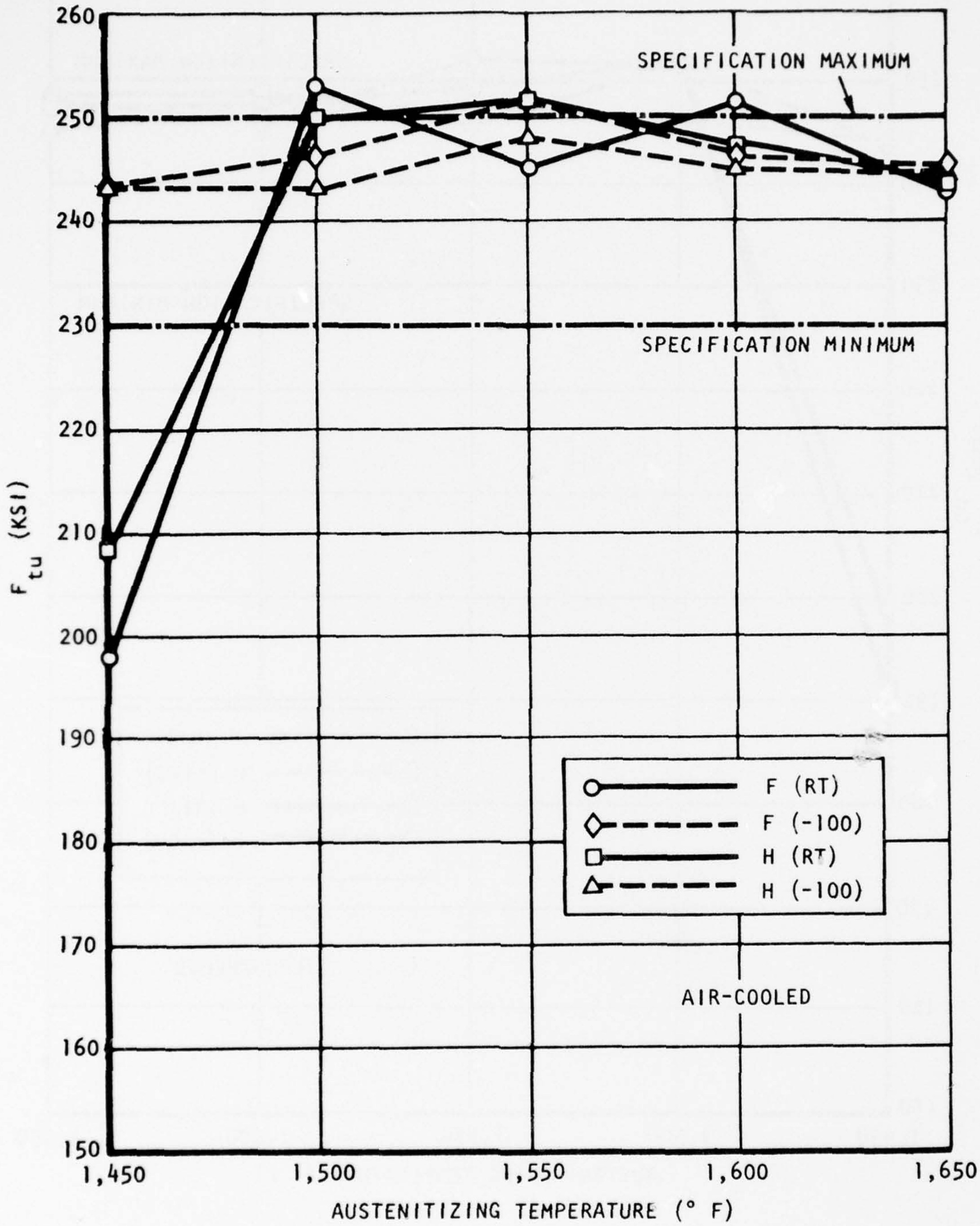


Figure 77 . F_{tu} Versus Austenitizing and Cooling Temperature for Air-Cooled AF1410 Steel

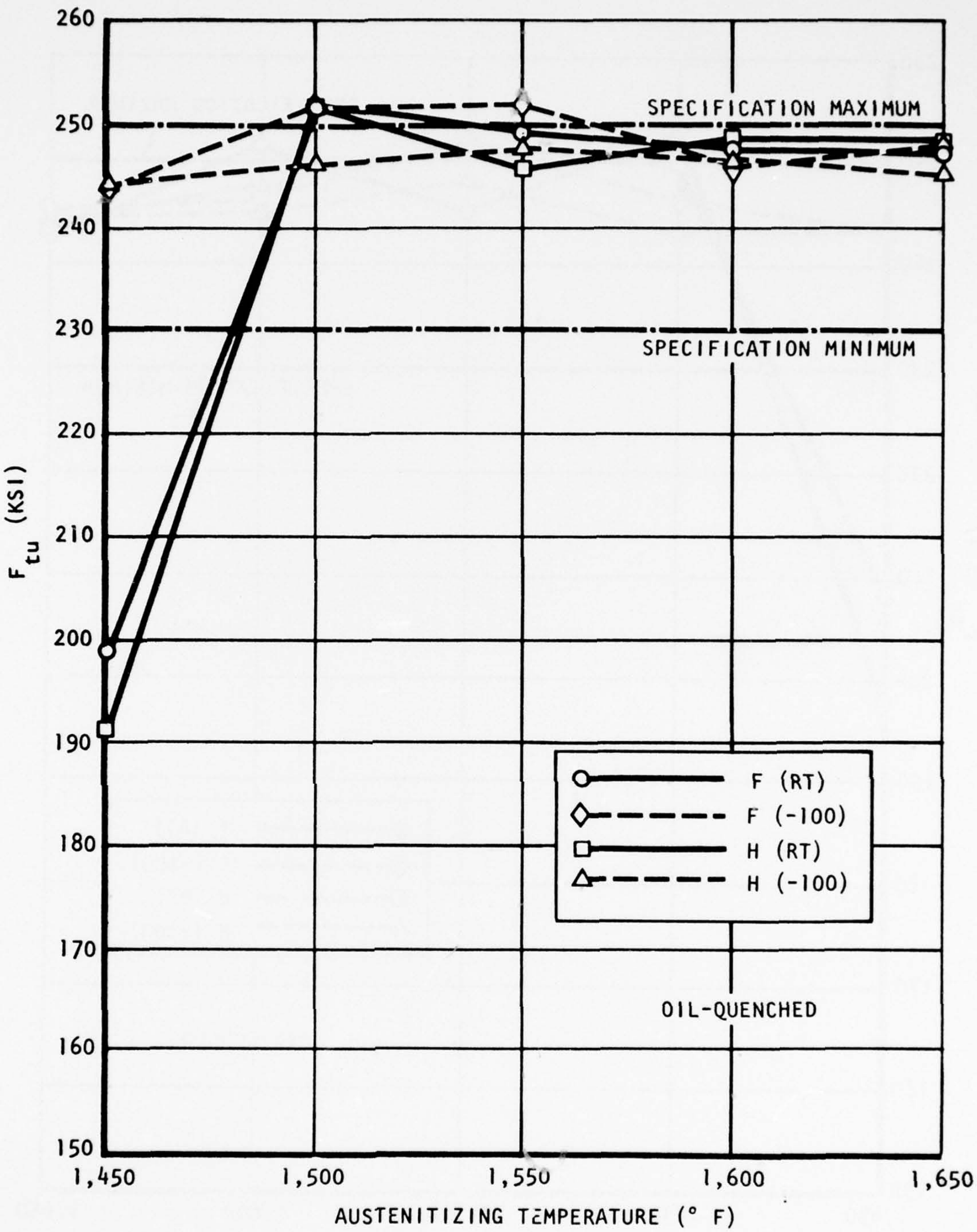


Figure 78. F_{tu} Versus Austenitizing and Cooling Temperature for Oil-Quenched AF1410 Steel

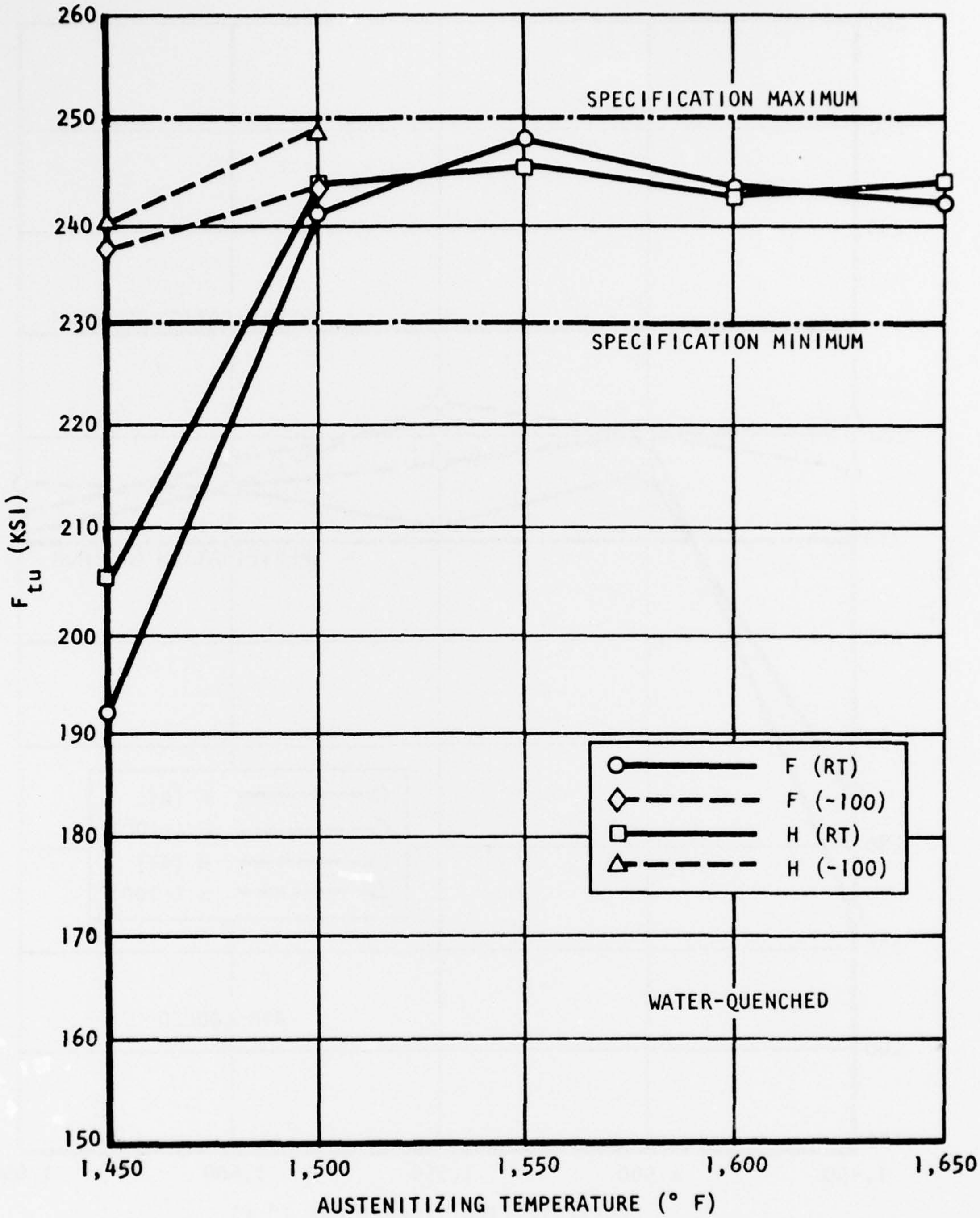


Figure 79 . F_{tu} Versus Austenitizing and Cooling Temperature for Water-Quenched AF1410 Steel

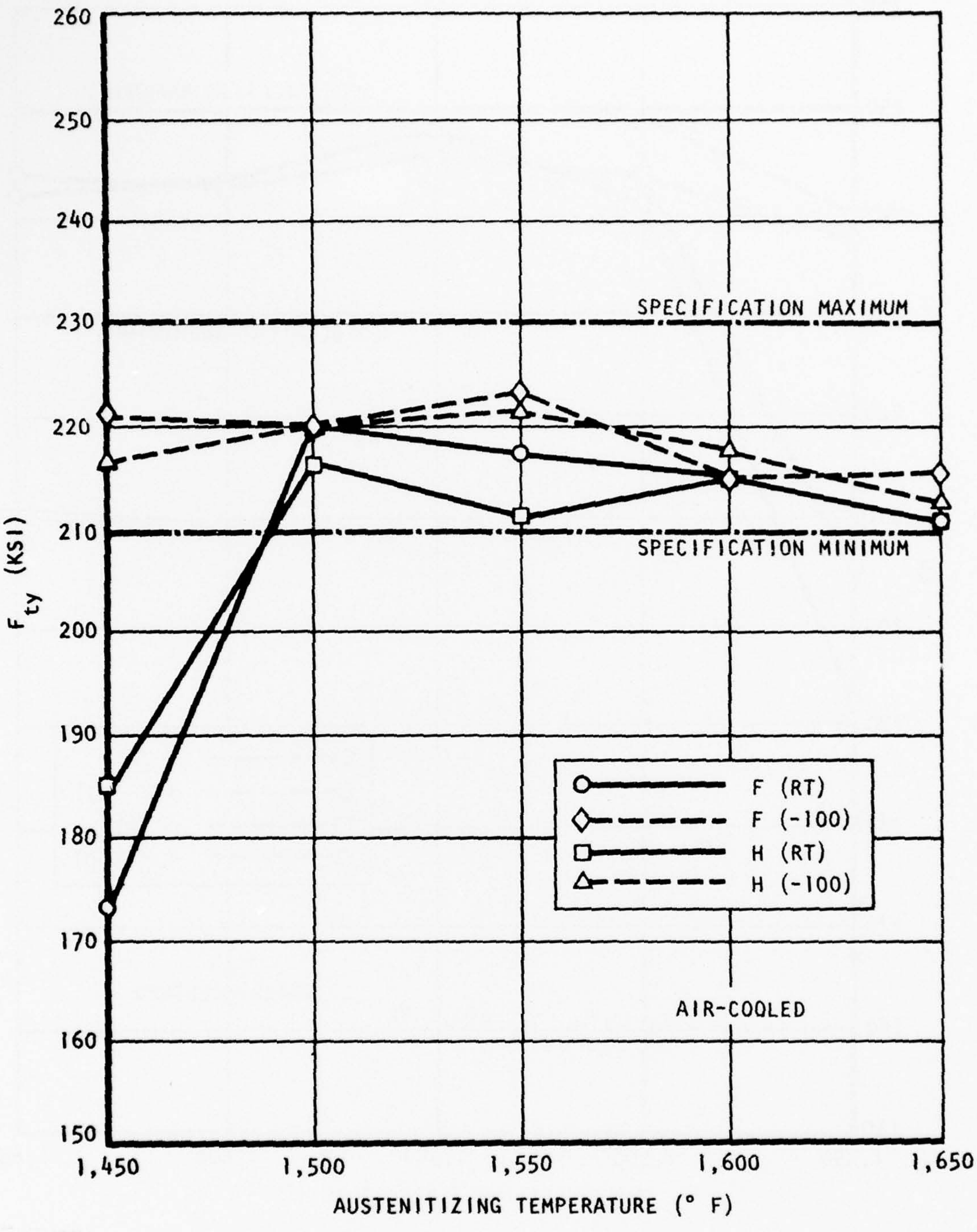


Figure 80. F_{ty} Versus Austenitizing and Cooling Temperature for Air-Cooled AF1410 Steel

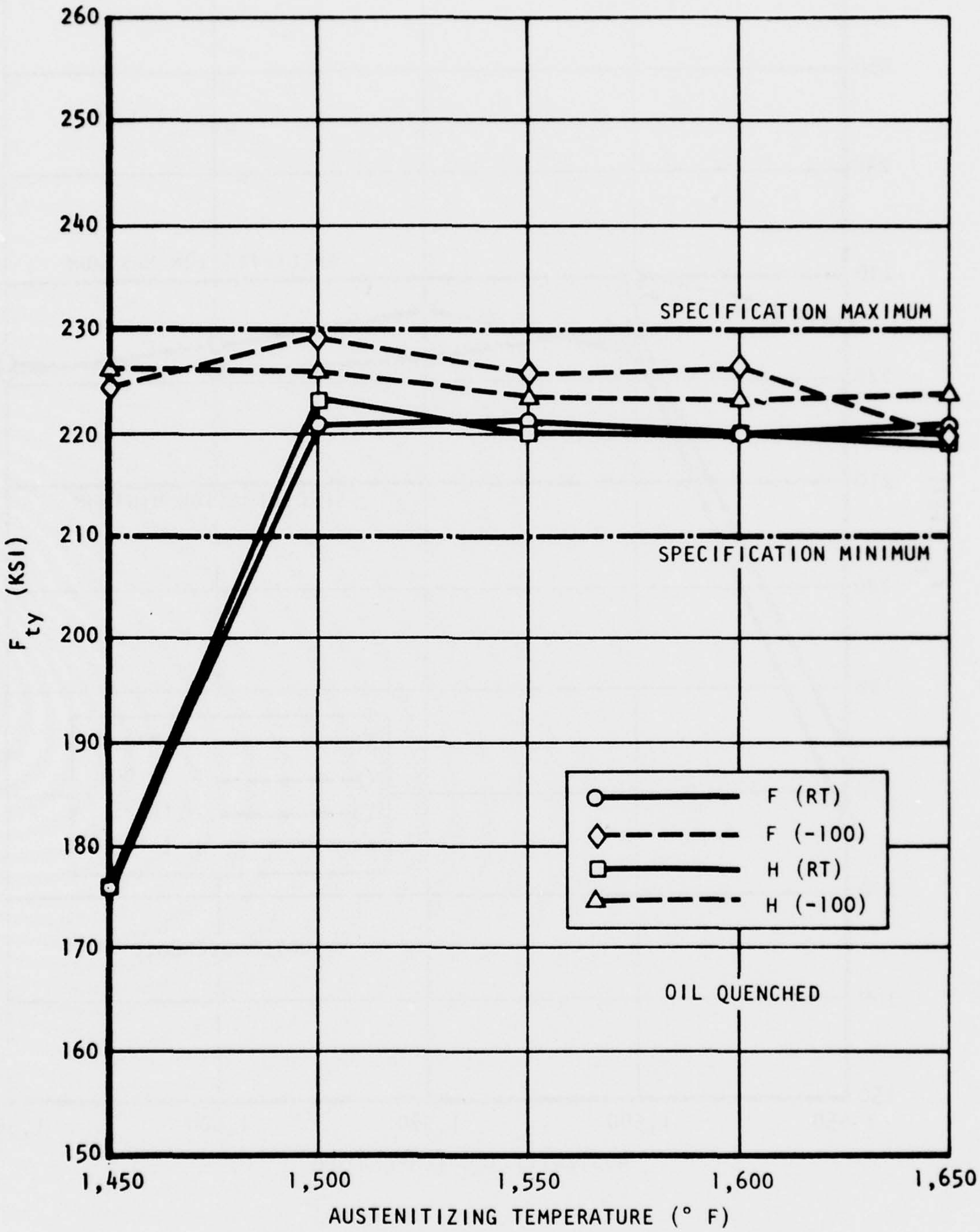


Figure 81. F_{ty} Versus Austenitizing and Cooling Temperature for Oil-Quenched AF1410 Steel

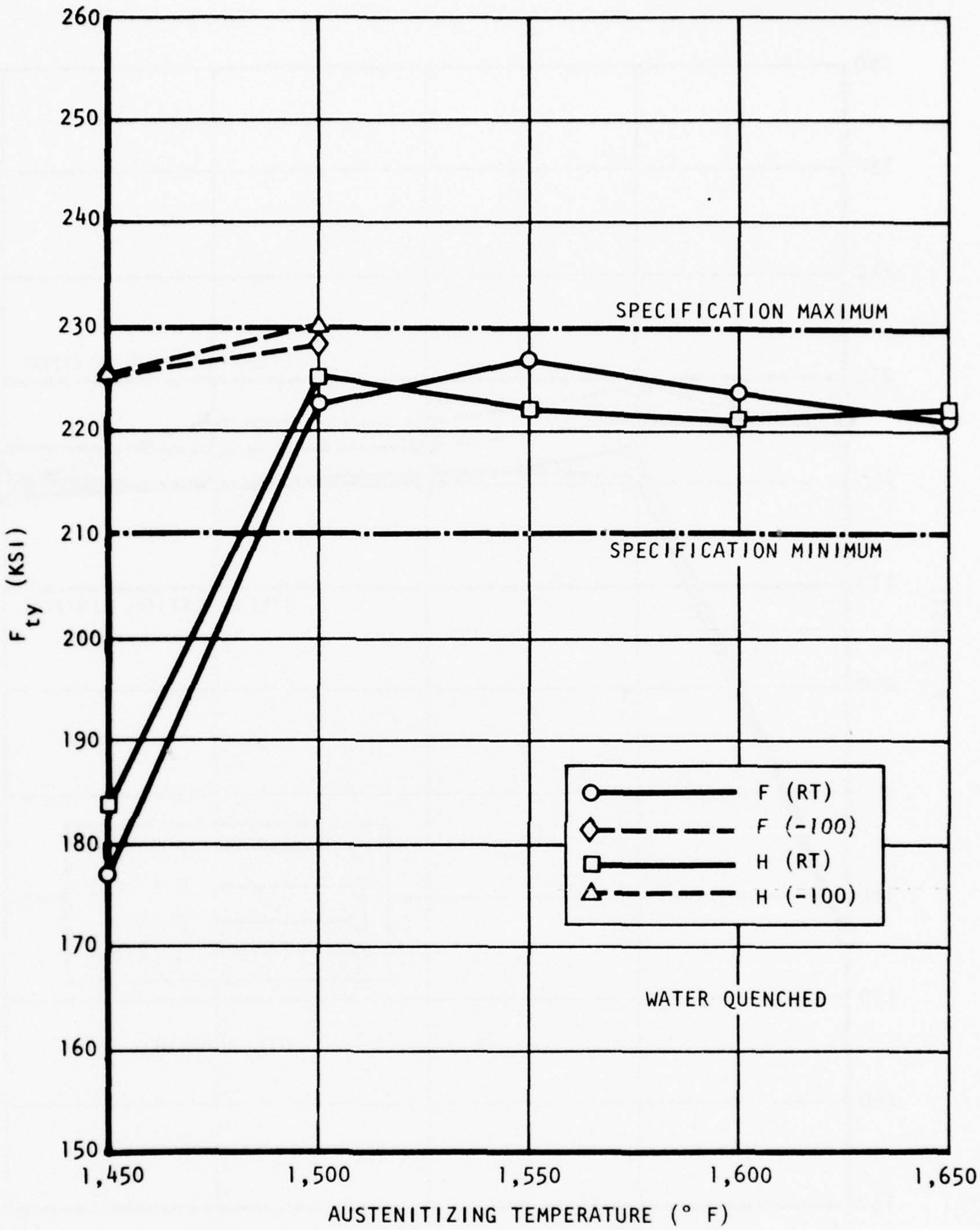


Figure 82. F_{ty} Versus Austenitizing and Cooling Temperature for Water-Quenched AF1410 Steel

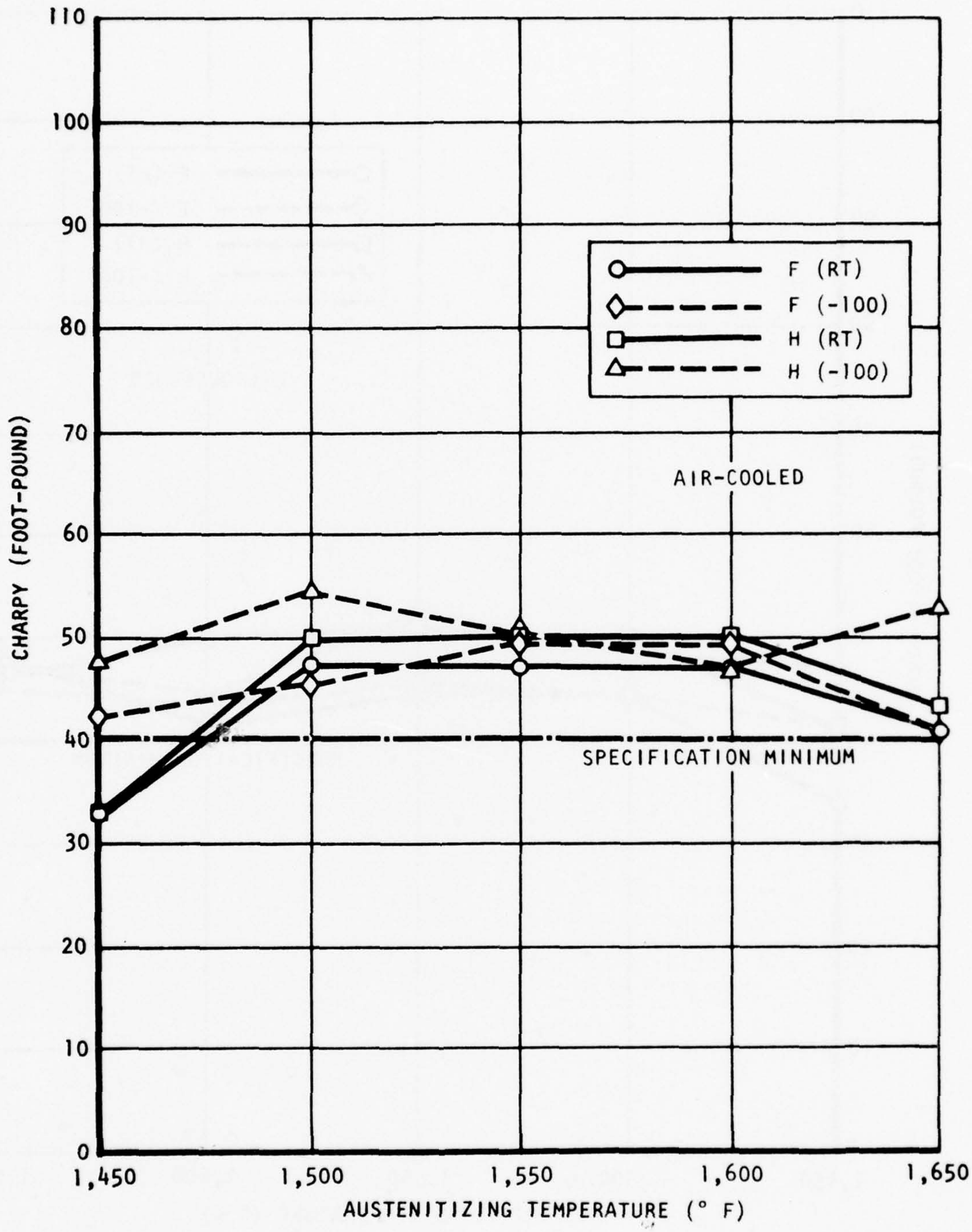


Figure 83. Charpy Impact Value Versus Austenitizing and Cooling Temperature for Air-Cooled AF1410 Steel

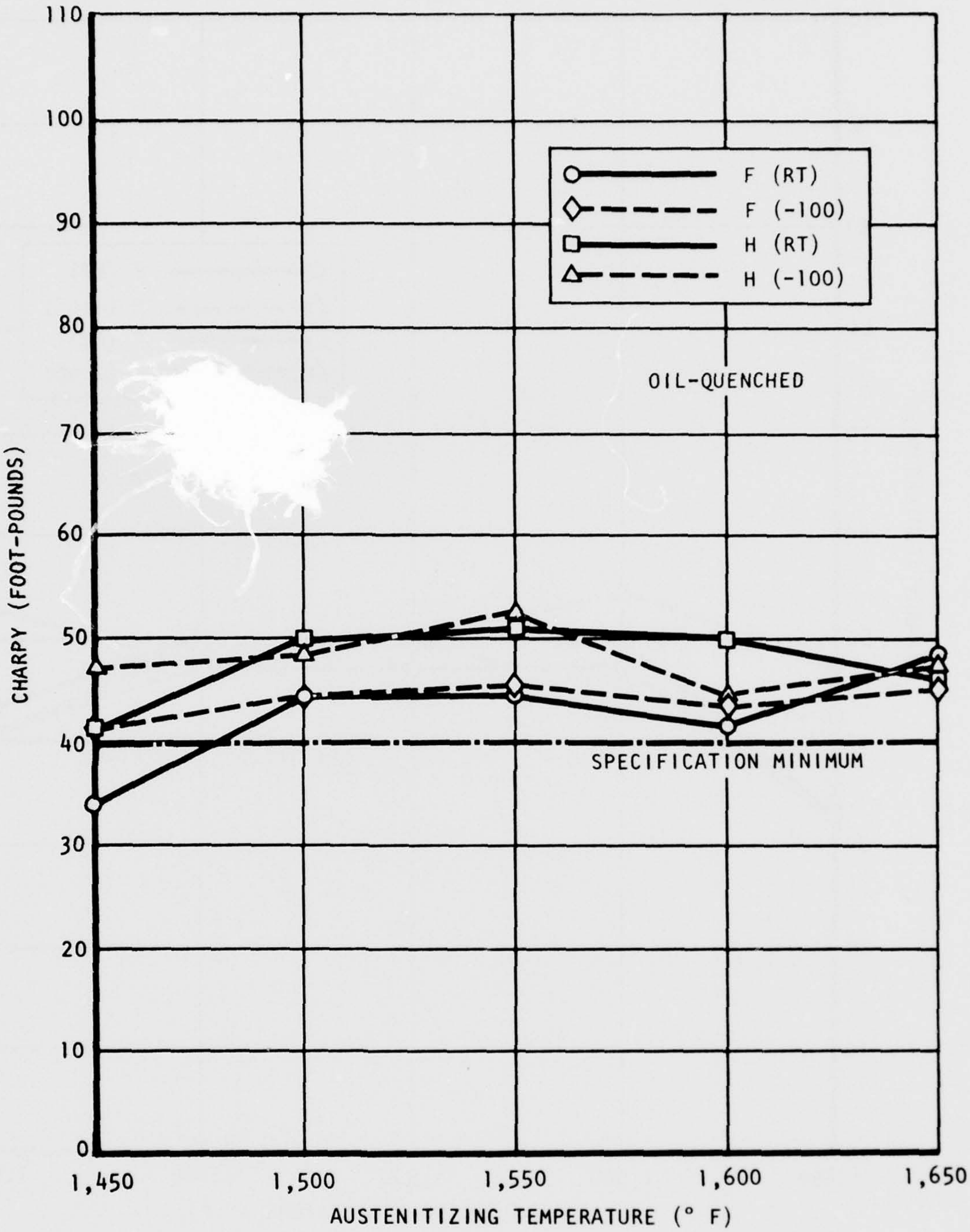


Figure 84 . Charpy Impact Value Versus Austenitizing and Cooling Temperature for AF1410 Steel

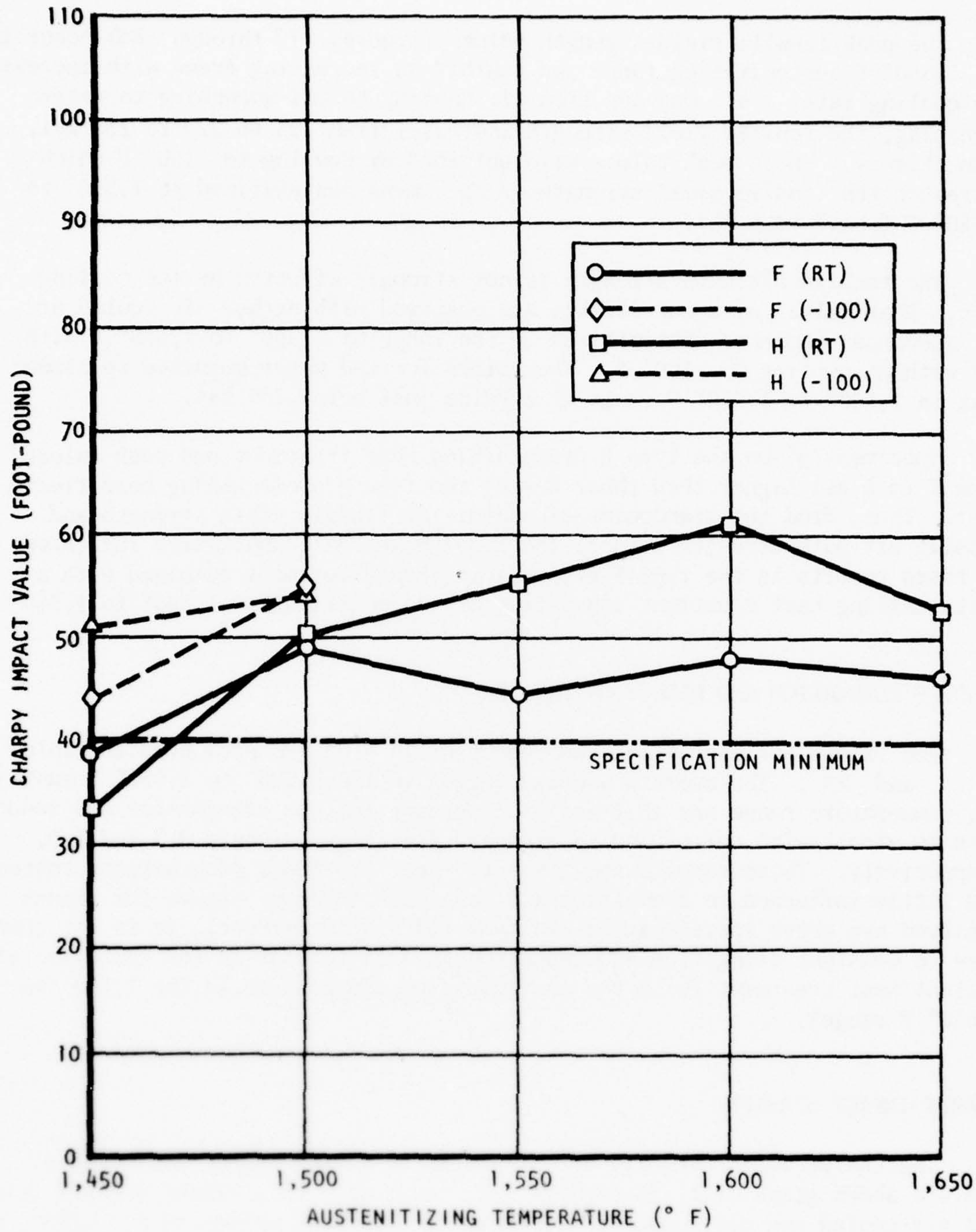


Figure 85. Charpy Impact Value Versus Austenitizing and Cooling Temperature for Water-Quenched AF1410 Steel

TENSILE ULTIMATE AND YIELDS

The peak tensile yield strength values (figures 77 through 82) occur in the 1,550° F austenitizing range and exhibit an increasing trend with increasing cooling rate; i.e., ongoing from air cooling to oil-quenching to water quenching, the tensile yield strength increases from 223 to 229 to 231 ksi, respectively. These peak values were obtained by cooling to -100° F which increased the tensile yield strength of specimens austenitized at 1,500° to 1,650° F from 3 to 8 ksi.

The tensile ultimate strength is not strongly affected by the cooling rate. Peak values of about 252 ksi are observed with either air-cooled or oil-quenched specimens austenitized in the range of 1,500° to 1,550° F with and without cooling to -100° F. The values for the water-quenched specimens peak in 1,500° to 1,550° F range at a value just below 250 ksi.

Specimens given the type F premachining heat treatment had peak values from 1 to 6 ksi higher than those having the type H premachining heat treatment. Thus, from the standpoint of maximizing tensile yield strength and tensile ultimate strength values, the final heattreat combination indicated by these results is the type F premachining heat treatment combined with a postmachining heat treatment consisting of austenitizing at 1,500° to 1,550° F.

TENSILE ELONGATION AND REDUCTION IN AREA

The values for elongation and reduction in area are presented in tables 50, 51, and 52. The overall average values in the 1,500° to 1,650° F austenitizing temperature range are 16.1 and 68.5 percent for the elongations and reduction in areas, with corresponding standard deviations of only 0.7 and 1.9, respectively. These results show that the heat treatment combinations tested had little influence on elongation and reduction in area. Since the values achieved are above specification minimums (14 and 60 percent), it is not necessary to consider elongation and reduction in area further in the selection of a final heat treatment (with the austenitizing temperature in the 1,500° to 1,650° F range).

CHARPY IMPACT STRENGTH

The Charpy impact results are presented in tables 50, 51, and 52 and are shown graphically in figures 83, 84, and 85. These results show the air-cooled and oil-quenched specimens to have peak values in the 1,500° to 1,550° F austenitizing range of near 54 feet-pounds, while the water-quenched peak value of 60 ksi occurs at an austenitizing temperature of 1,600° F. In all cases, the peak value occurred when the type H premachining heat treatment was used. The type F premachining heat treatment yielded peak Charpy values that were approximately 5 foot-pounds less than the type H peak values.

The effect of cooling to -100° F on the Charpy impact value is not significant except in the 1,450° to 1,550° F austenitizing temperature range where peak tensile ultimate strength and tensile yield strength values are not achieved. In the lower end of the 1,450° to 1,550° F range, cooling to -100° F caused the tensile ultimate strength, tensile yield strength, and Charpy impact values to increase on the order of 25 percent.

HARDNESS

Hardness measurements were made on polished and etched sections. The results show a hardness range from 42.1 to 50.8 R_c. Specimens austenitized in the range from 1,500° to 1,650° F had hardness values in the range of 48.2 to 50.8 R_c, regardless of the quenching medium or subzero treatment. Specimens austenitized at 1,450° F had hardness values in the range of 40.7 to 43.8 R_c, regardless of the quenching medium if not given the subzero treatment. If given the subzero treatment, the hardness values for the 1,450° F austenitized specimens increased to within the 48.2 to 50.8 R_c range. Apparently, the additional martensite transformation that occurs during the subzero treatment is sufficient to bring the hardness level up to that of the specimens austenitized at 1,500° F and above.

DISCUSSION

The purpose of the phase II effort is to establish a quench and temper heat treatment for AF1410 steel which (1) is compatible with selected premachining heat treatments developed in phase I to permit maximum metal removal rates, (2) permits adequate control of finished part dimension, (3) results in satisfactory properties in the 230 to 250 ksi heat-treat range, and (4) is compatible with acceptable weldment mechanical properties.

Selection of the final combination of premachining and postmachining heat treatments was made on the basis of obtaining the maximum tensile ultimate strength and tensile yield strength and impact properties commensurate with the previsouly mentioned considerations. The selection necessarily is tentative since compatibility with weldment mechanical properties has yet to be determined and valid fracture toughness tests must be made to establish that the K_{Ic} value is satisfactory; however, no significant alterations in the selected heat treat sequences are anticipated as a result of these tests.

The use of an oil quench is being selected over that of a water quench primarily because the increased distortion associated with the latter would typically necessitate additional finish machining, thereby increasing cost. Although the 60-foot-pound Charpy impact value is desirable, its attainment in thick sections is conditional on obtaining the same cooling rate as was obtained in the 1-inch-thick test sections. This is questionable at this time.

Table 53
HARDNESS TEST RESULTS ON AF 1410 STEEL SPECIMENS VARIOUSLY HEAT TREATED

Heat-Treat Variations		Air Cooled			Oil Quenched			Water Quenched		
Aust Temp (° F)	Cooled to	Spec Ident	Hardness (R_C) X	Hardness (R_C) σ	Spec Ident	Hardness (R_C) X	Hardness (R_C) σ	Spec Ident	Hardness (R_C) X	Hardness (R_C) σ
1,450	RT	F-1	42.6	0.5	F-3	42.1	0.8	F-6	42.4	0.4
1,500	RT	F-7	50.8	0.2	F-9	50.7	0.6	F-11	48.8	0.4
1,550	RT	F-13	49.7	0.5	F-15	49.9	0.2	F-27	48.4	0.4
1,600	RT	F-17	49.4	0.3	F-19	48.8	0.6	F-21	49.6	0.3
1,650	RT	F-22	48.4	0.6	F-24	48.4	1.0	F-26	48.6	0.4
1,450	-100	F-2	48.3	0.2	F-4	49.4	0.4	F-5	48.9	0.3
1,500	-100	F-8	49.3	0.3	F-10	50.0	1.4	F-12	49.3	0.9
1,550	-100	F-11	50.4	0.4	F-16	49.1	0.9	-	-	-
1,600	-100	F-18	48.3	0.9	F-20	49.6	1.0	-	-	-
1,650	-100	F-23	48.7	0.4	F-25	49.4	0.4	-	-	-
1,450	RT	H-1	43.8	0.3	H-6	40.7	0.3	H-3	43.5	0.7
1,500	RT	H-7	50.4	0.6	H-9	50.5	0.4	H-11	48.8	0.5
1,550	RT	H-13	49.1	0.3	H-15	48.6	0.7	H-27	48.6	0.6
1,600	RT	H-17	49.0	0.6	H-19	48.4	0.4	H-21	48.2	0.5
1,650	RT	H-22	48.5	0.5	H-24	48.7	0.5	H-26	48.7	0.5
1,450	-100	H-2	49.4	0.2	H-4	48.8	0.4	H-5	48.9	0.2
1,500	-100	H-8	49.7	0.2	H-10	49.5	0.4	H-12	48.8	0.2
1,550	-100	H-14	49.5	0.2	H-16	49.5	0.6	-	-	-
1,600	-100	H-18	48.8	0.4	H-20	48.7	0.4	-	-	-
1,650	-100	H-23	48.6	0.5	H-25	48.3	0.6	-	-	-
								PM + STD	49.4	0.5

*All specimens aged at 950° F for 5 hours and then air cooled.
**Average value of four tests.

The type F premachine heat treatment was selected because of the more favorable tensile ultimate strength and tensile yield strength values resulting from its use and, from a cost standpoint, because it is less complicated and involves less furnace time than the type H premachine treatment. The relative flatness of the curves (figures 77 through 85) beyond the 1,550° F austenitizing temperature indicates that the reproducibility of the selected heat treatment will be good.

As a result of the foregoing considerations, the tentative selection of the final AF1410 steel heattreat combination was determined to be the type F premachining heat treatment in conjunction with the following postmaching heat treatment:

1. Austenitize at 1,650° F

2. Air-cool

3. Austenitize at 1,525° (±25°) F

4. Oil quench

5. Cool to -100° F for 2 hours

6. Age at 950° F for 5 hours

7. Air-cool

WORK IN PROGRESS

Task 2 effort is underway to establish the effect of varying the aging temperatures (of the selected postmachining heat treatment) within the range of 925° to 975° F. Eleven 1-inch by 2-inch by 6-inch specimens of AF 1410 steel have been cut from as-received stock and are currently being heattreated. Evaluation will be on the basis of tensile and Charpy impact tests and metallographic inspection.

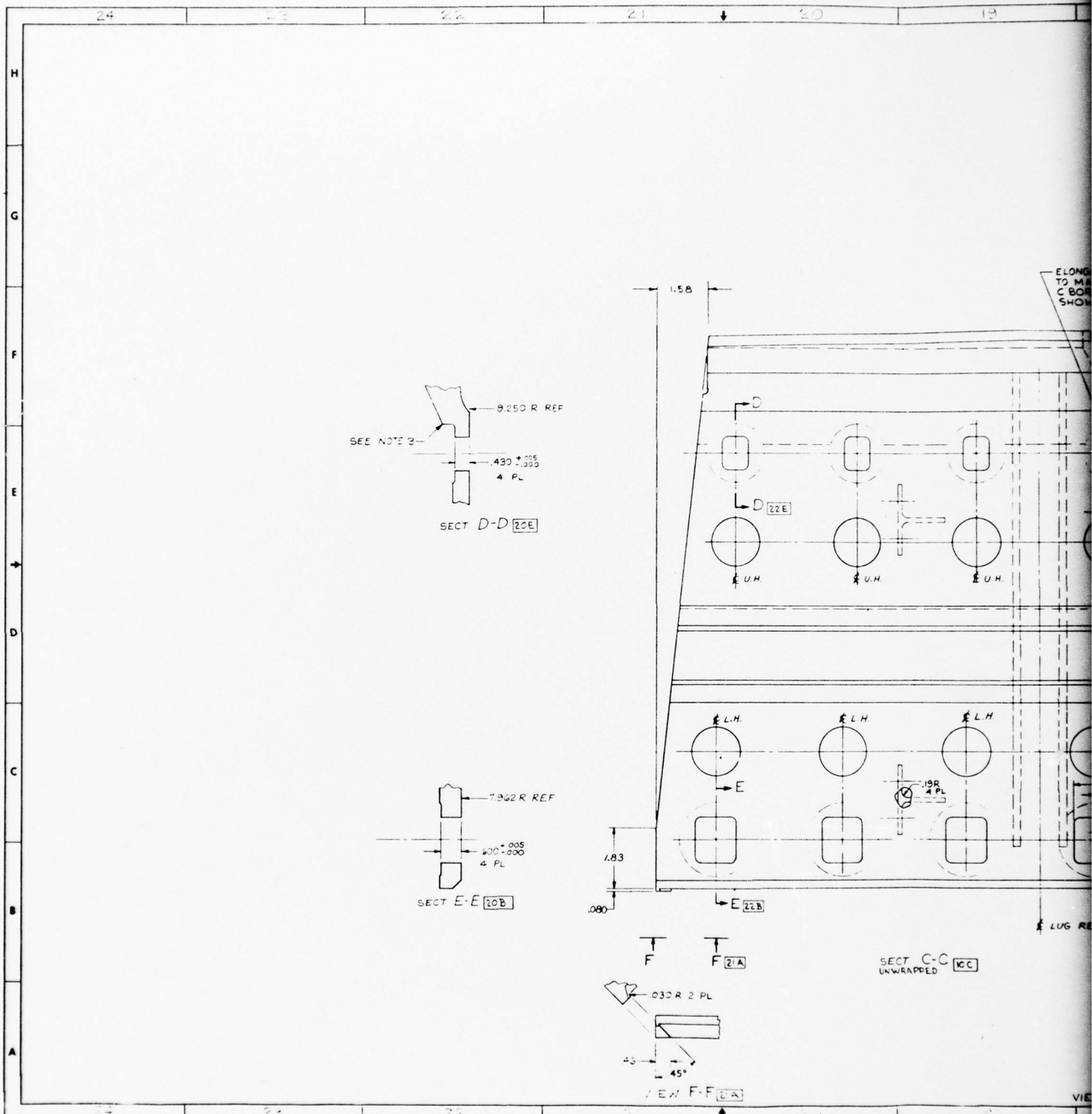
Two pairs of welding specimens, 5/8 by 3 by 15 inches, have been machined and will shortly be given the type F premachining heat treatment. As soon as the aging temperature of the postmachining heat treatment is determined, two weld specimens will be prepared, heattreated, and tested.

Fracture toughness specimens are currently being prepared. These will be tested to determine K_{Ic} values during the next reporting period.

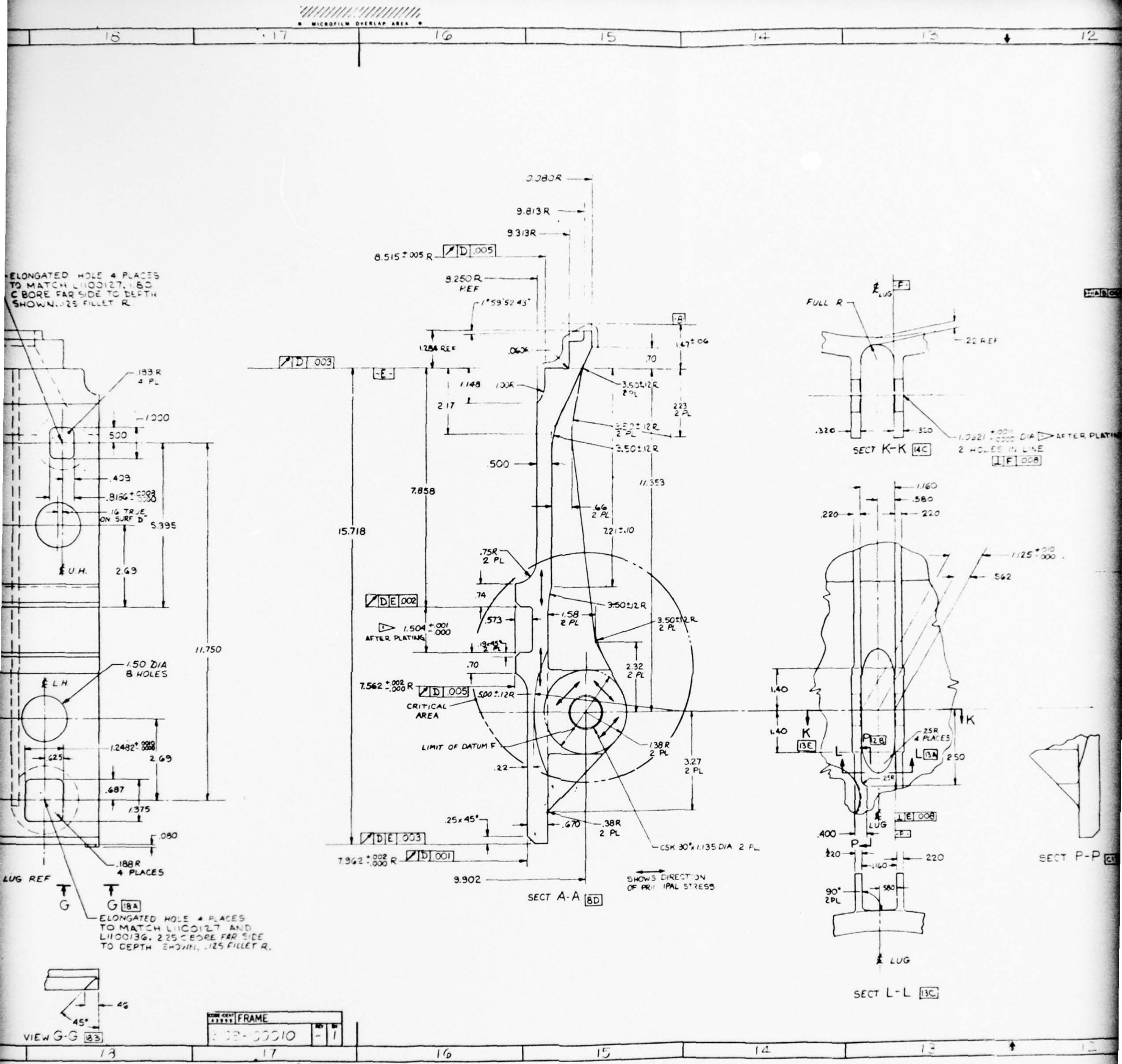
APPENDIX A

DRAWINGS - COMPONENTS

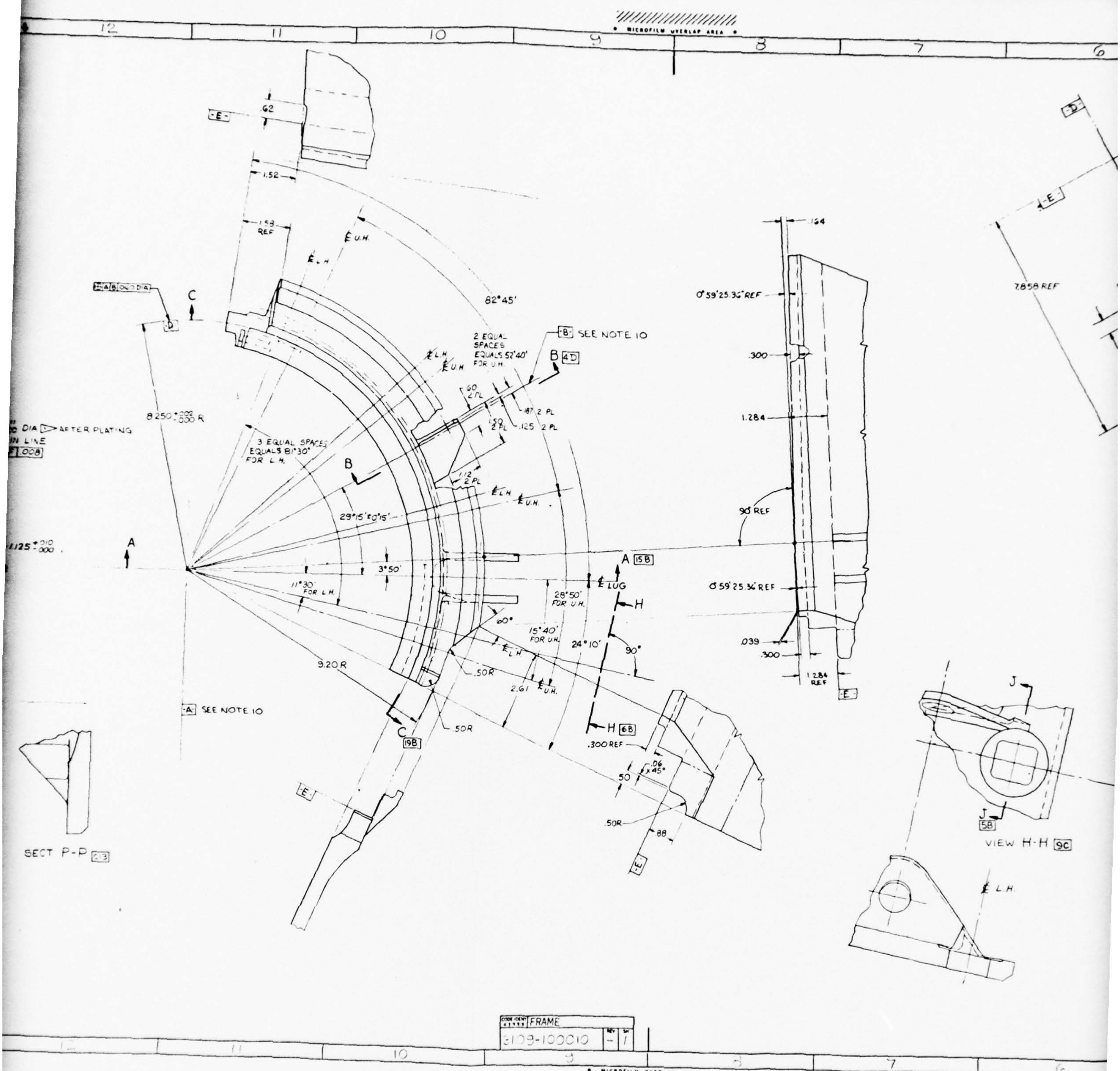
Preceding Page Blank - Fi



24
23
22
21
20
19
H
G
F
E
D
C
B
A
1.58
8.250 R REF
SEE NOTE 3
.430 +.005 -.000
4 PL
SECT D-D 20E
D
D 22E
℄ U.H.
℄ U.H.
℄ U.H.
℄ L.H.
℄ L.H.
℄ L.H.
E
E 22B
.19R
4 PL
7.962 R REF
.600 +.005 -.000
4 PL
SECT E-E 20B
1.83
.080
F
F 21A
SECT C-C 10C
UNWRAPPED
.030 R 2 PL
.43
45°
VIEW F-F 21A



MICROFILM OVERLAP AREA
ELONGATED HOLE 4 PLACES TO MATCH L1100127. 1.60 C BORE FAR SIDE TO DEPTH SHOWN. .125 FILLET R.
.188 R 4 PL
1.000
.500
.409
.8156
.16 TRUE ON SURF D
5.395
℄ U.H.
2.69
11.750
1.50 DIA 8 HOLES
℄ L.H.
1.2482
.625
.687
.375
.080
.188 R 4 PLACES
LUG REF
G
G 18A
ELONGATED HOLE 4 PLACES TO MATCH L1100127 AND L1100136. 2.25 C BORE FAR SIDE TO DEPTH SHOWN. .125 FILLET R.
45°
VIEW G-G 18B
FRAME
9.813 R
9.313 R
8.515 ±.005 R
9.250 R REF
1°59'52.43"
1.284 REF
.0606
1.47 ±.06
.70
D .003
E
1.148
.100R
3.50 ±.12 R 2 PL
2.17
2.23 2 PL
3.50 ±.12 R
.500
7.858
11.353
15.718
.66 2 PL
7.21 ±.10
.75R 2 PL
.74
DE .002
.573
1.58 2 PL
3.50 ±.12 R
3.50 ±.12 R 2 PL
1.504 +.001 -.000 AFTER PLATING
.70
2.32 2 PL
7.562 +.002 -.000 R
D .005
.500 ±.12R
CRITICAL AREA
LIMIT OF DATUM F
.138 R 2 PL
3.27 2 PL
.22
.25x45°
.670
.38R 2 PL
DE .003
7.962 +.002 -.000 R
D .001
9.902
CSK 90° x 1.135 DIA 2 PL
SHOWS DIRECTION OF PRINCIPAL STRESS
SECT A-A 8D
FULL R
℄ LUG
F
.22 REF
.320
.320
1.0021 +.0011 -.0000 DIA AFTER PLATING 2 HOLES IN LINE
SECT K-K 14C
F .008
1.160
.580
.220
.220
1.125 +.010 -.000
.562
1.40
1.40
K 13E
K
P 12B
.25R 4 PLACES
L
L 13A
2.50
.25R
℄ LUG
E .008
.400
P
.220
.160
.220
90° 2 PL
.580
℄ LUG
SECT L-L 13C
SECT P-P



MICROFILM OVERLAP AREA
SEE NOTE 10
2 EQUAL SPACES EQUALS 52°40' FOR U.H.
3 EQUAL SPACES EQUALS 81°30' FOR L.H.
82°45'
29°15'±0°15'
3°50'
11°30' FOR L.H.
28°50' FOR U.H.
15°40' FOR U.H.
24°10'
90°
60°
9.20 R
.50R
2.61
.300 REF
A SEE NOTE 10
SECT P-P
VIEW H-H
90° REF
0°59'25.36" REF
1.284
.300
.039
7.858 REF
AFTER PLATING
FRAME
3109-100010

2

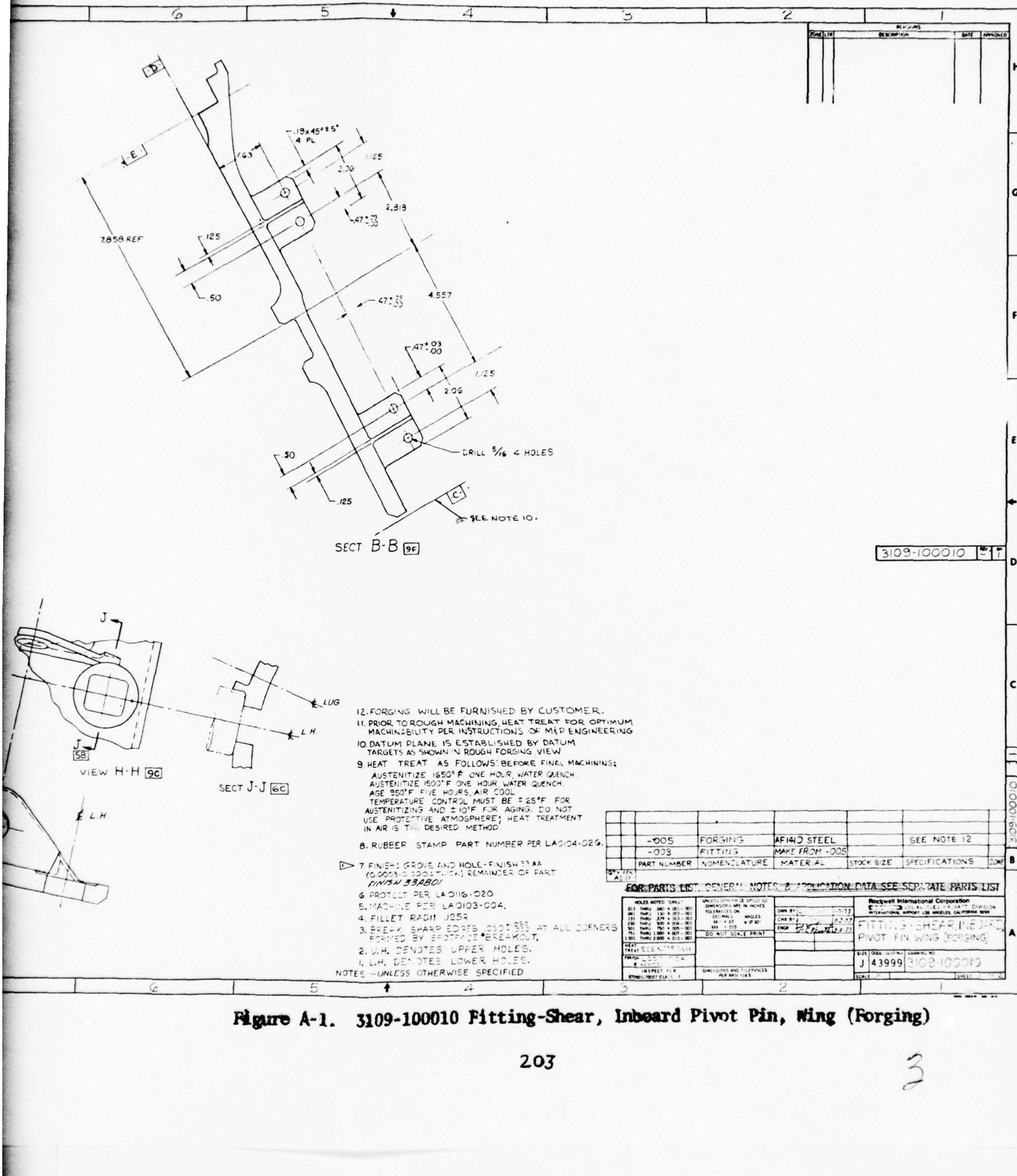
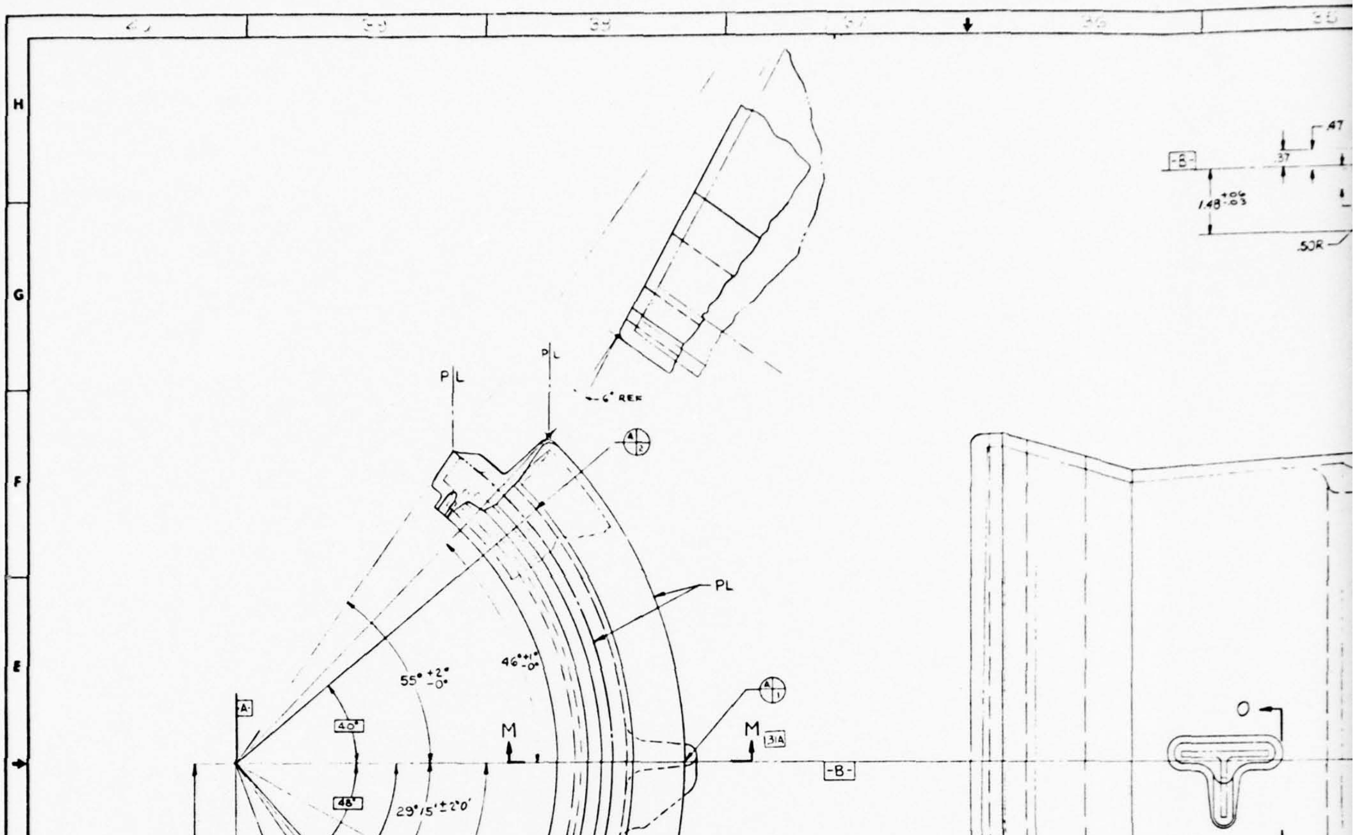


Figure A-1. 3109-100010 Fitting-Shear, Inboard Pivot Pin, Wing (Forging)

3



P L
6° REF
PL
55° +2° -0°
46° +1° -0°
40°
48°
29° 15' ± 2' 0'
50° 55' ± 2' 0'
M
M 13IA
-A-
-B-
N
N 27C
55° +2° -0°
7.086
8.95 ± .16 R
8.950 R
FOR DATUM TARGETS
4.961
1.10 +.12 -.03
1.00 +.12 -.03
2.56 ± .09
.47 +.06 -.03
2.56
1.28 REF
1.48 +.06 -.03
.37
.47
.50R
O
O 35F

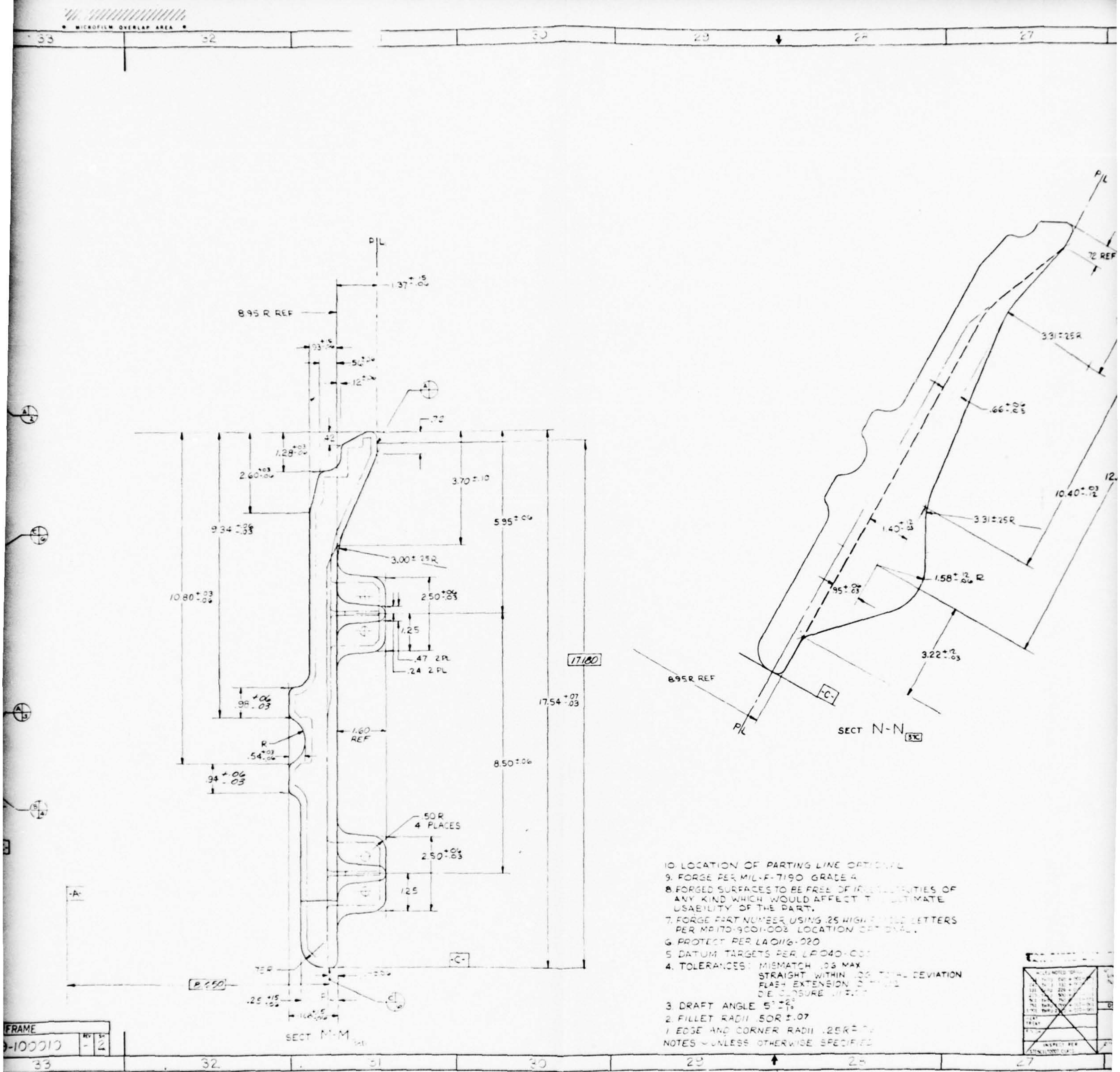


Figure A-1. 3109-100010 Fitti
Pivot Pin, Wing (Forgi

2

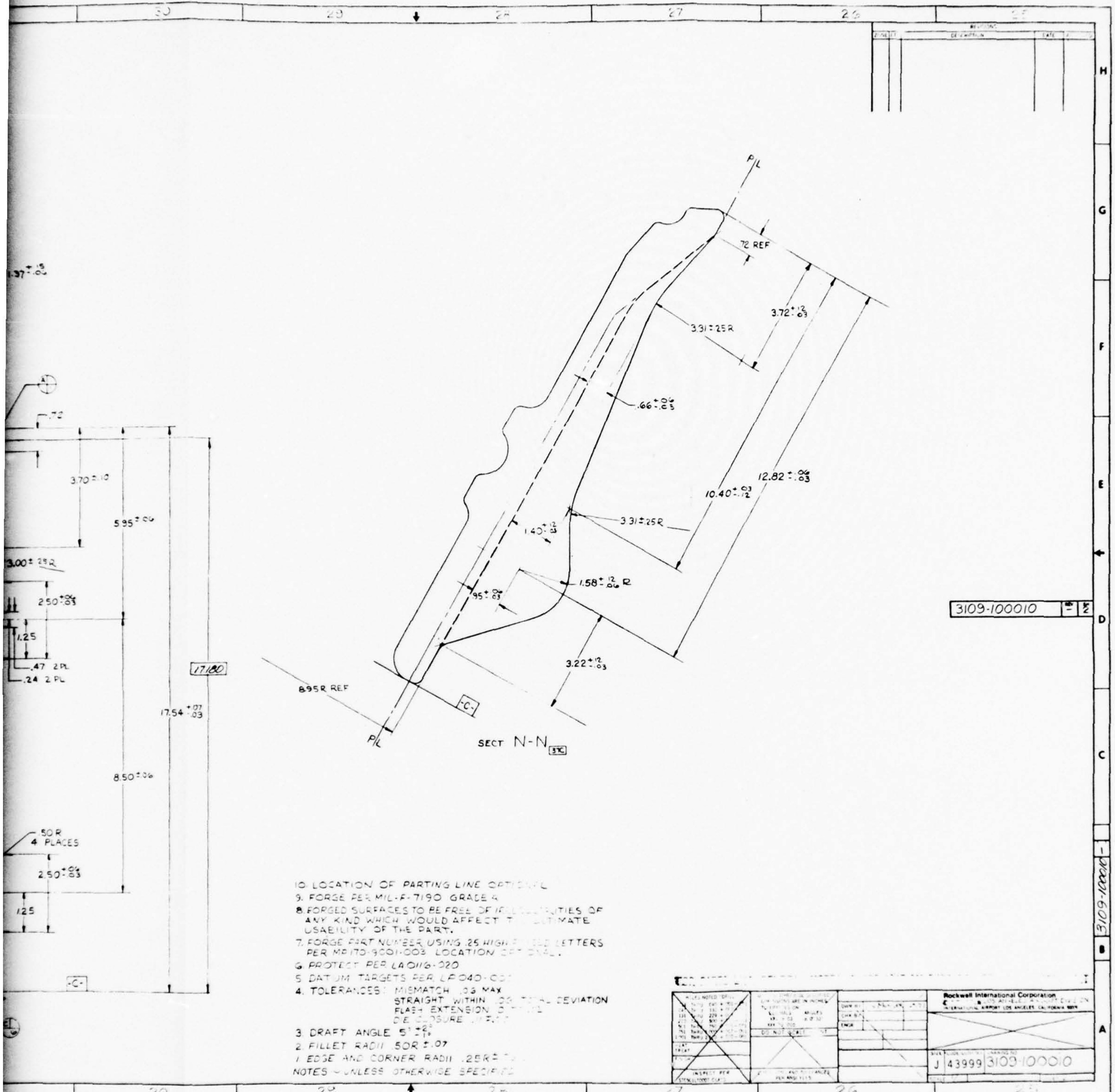
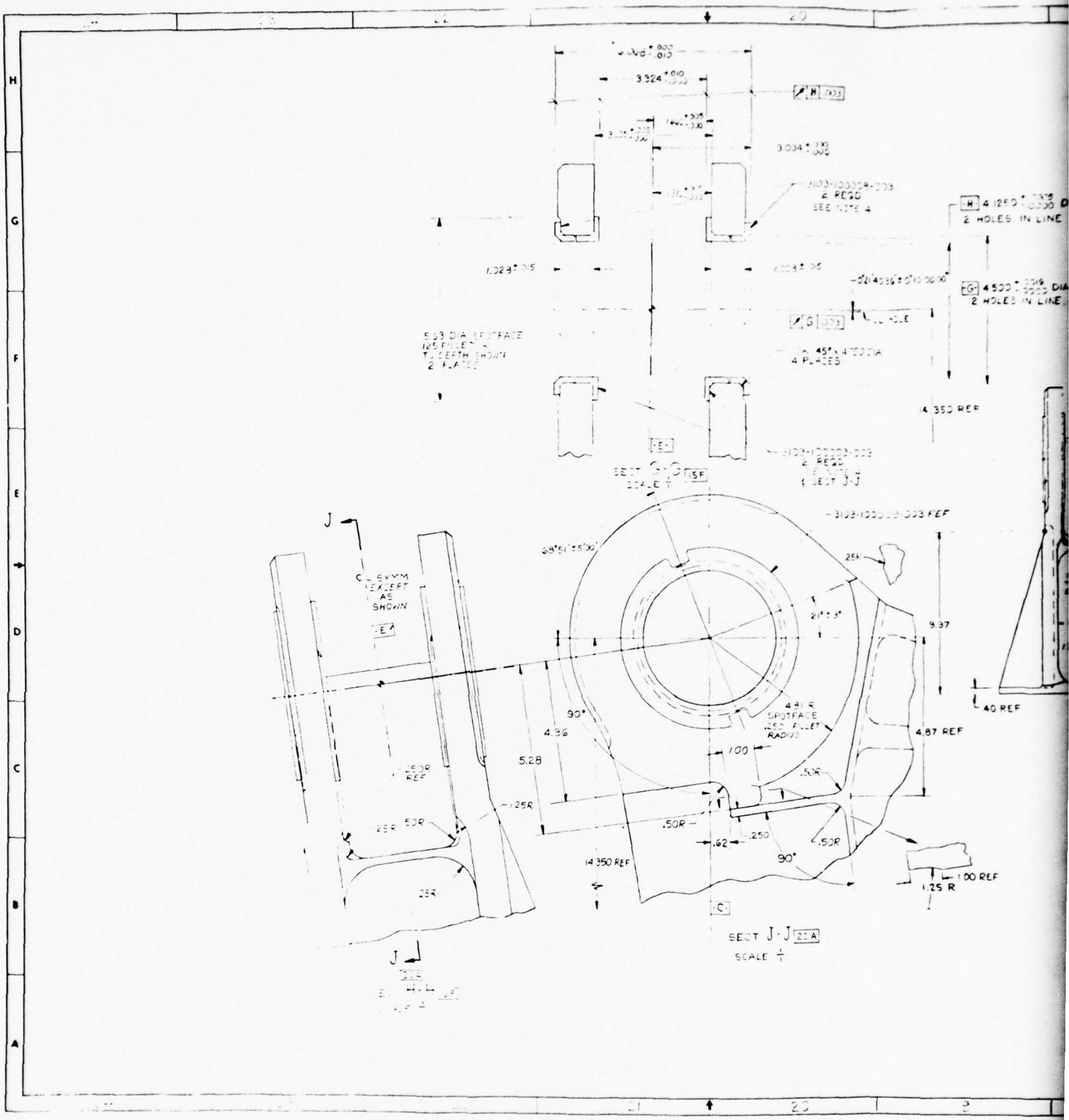
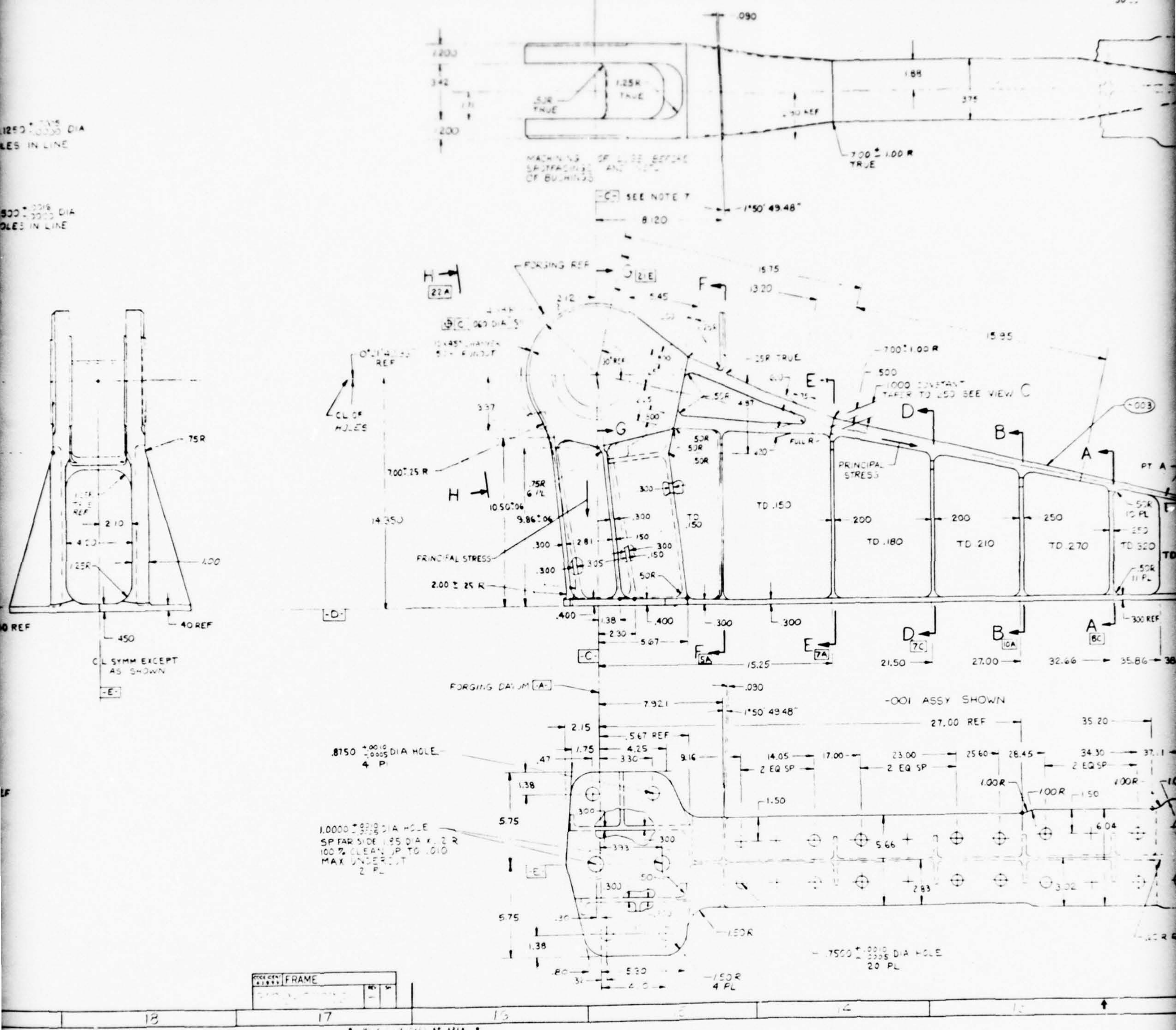


Figure A-1. 3109-100010 Fitting-Shear, Inboard Pivot Pin, Wing (Forging) (Concluded)

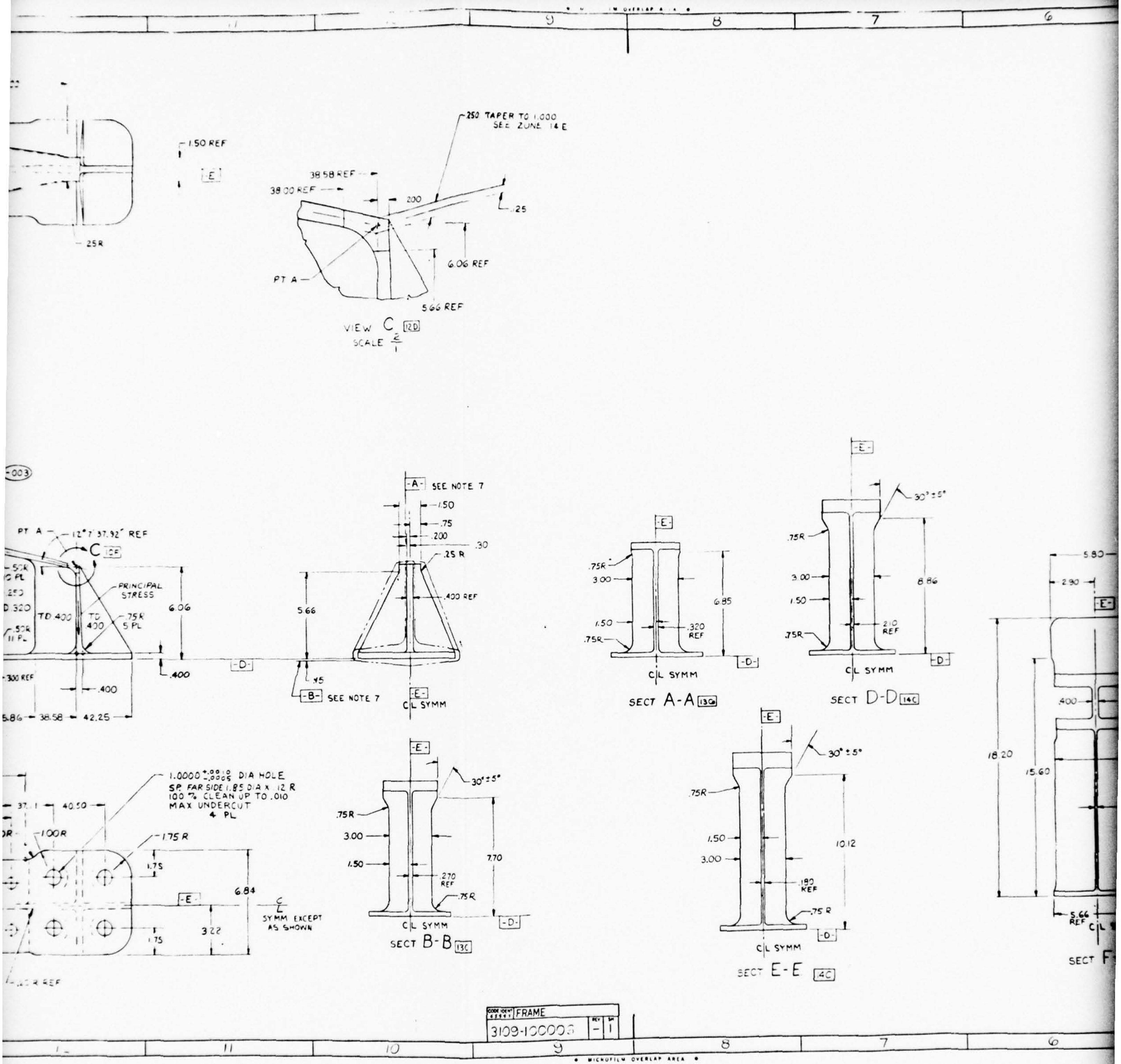
3



SECT G-G 15F
SCALE 1/1
5.63 DIA SPOTFACE
.125 FILLET R
TO DEPTH SHOWN
2 PLACES
2 HOLES IN LINE
14.350 REF
4.81 R
SPOTFACE
.250 FILLET
RADIUS
4.87 REF
.40 REF
9.37
4.36
5.28
1.00
.50R
.25R
.125R
.62
.250
90°
1.00 REF
1.25 R
14.350 REF
SECT J-J 22A
SCALE 1/1

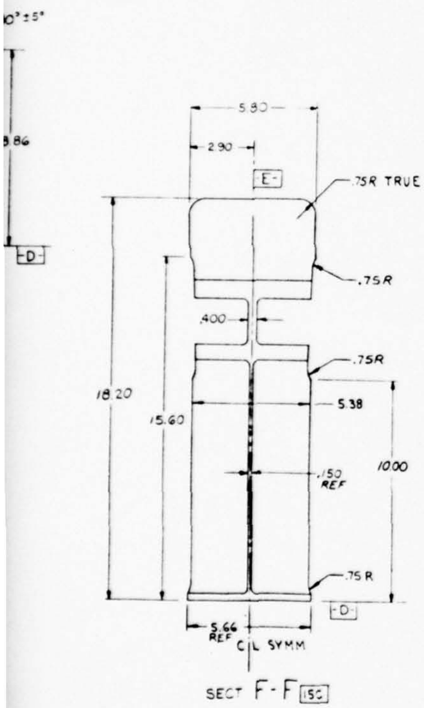

FRAME
-001 ASSY SHOWN
FORGING DATUM -A-
FORGING REF
PRINCIPAL STRESS
C/L SYMM EXCEPT AS SHOWN
CL OF HOLES
SEE NOTE 7
TD .150
TD .180
TD .210
TD .270
TD .320
.8750 DIA HOLE 4 PL
.7500 DIA HOLE 20 PL
1.50R 4 PL
7.00 ± 1.00 R TRUE
1°50' 49.48"
8.120
7.921
15.25
21.50
27.00
32.66
35.86
27.00 REF
35.20

2


.250 TAPER TO 1.000 SEE ZONE 14 E
VIEW C 12D
SCALE 2/1
PT A
38.58 REF
38.00 REF
6.06 REF
5.66 REF
PT A — 12° 7' 37.92" REF
PRINCIPAL STRESS
SEE NOTE 7
C/L SYMM
SECT A-A 13G
SECT D-D 14C
SECT B-B 13C
SECT E-E 14C
30° ± 5°
1.0000 +.0010 -.0005 DIA HOLE
SP. FAR SIDE 1.85 DIA x .12 R
100 % CLEAN UP TO .010
MAX UNDERCUT
4 PL
C/L SYMM EXCEPT AS SHOWN
SECT F
FRAME
3109-100003

2

3



12. FORGING WILL BE FURNISHED BY CUSTOMER
11. PRIOR TO ROUGH MACHINING, HEAT TREAT FORGING FOR OPTIMUM MACHINABILITY PER INSTRUCTIONS OF M&P ENGINEERING.
10. MACHINE FILLET RADIUS .25
9. PROTECT PER LA0116-020
8. FINISH -003 AS FOLLOWS: ABRASIVE CLEAN PER ST0109GA0001 AND APPLY FINISH HA01.
7. DATUM PLANE IS ESTABLISHED BY DATUM TARGETS AS SHOWN IN ROUGH FORGING VIEW
6. HEAT TREAT AS FOLLOWS BEFORE FINAL MACHINING:
   AUSTENITIZE 1650°F ONE HOUR, WATER QUENCH.
   AUSTENITIZE 1500°F ONE HOUR, WATER QUENCH.
   AGE 950°F FIVE HOURS, AIR COOL.
   TEMPERATURE CONTROL MUST BE ±25°F FOR AUSTENITIZING AND ±10°F FOR AGING. DO NOT USE PROTECTIVE ATMOSPHERE; HEAT TREATMENT IN AIR IS THE DESIRED METHOD.
5. TD DENOTES THICKNESS DIMENSION.
4. INSTALL BUSHINGS PER ST0 LA0004.
3. RUBBER STAMP PART NO. PER LA0104-022.
2. MACHINE PER LA0103-004.
1. FRACTURE CONTROL PART CATEGORY I.

NOTES - UNLESS OTHERWISE SPECIFIED

					-005	FORGING	AF 1410 STEEL	SEE NOTE 12
				2	3109-10003-003	BUSHING		
				2	3109-10008-003	BUSHING		
				1	-003	FITTING	MAKE FROM -005 FORGING	
				-001	DASH NUMBER	PART NAME	MATERIAL	SPECIFICATIONS

QTY REQD/DASH NO

FOR PARTS LIST, GENERAL NOTES, & APPLICATION DATA SEE SEPARATE PARTS LIST

HOLES NOTED DRILL
013 THRU 040 +.001 -.001
041 THRU 130 +.002 -.001
131 THRU 229 +.003 -.001
230 THRU 500 +.004 -.001
501 THRU 750 +.005 -.001
751 THRU 1.000 +.007 -.001
1.001 THRU 2.000 +.010 -.001

HEAT TREAT NOTED
FINISH LO000024 & NOTED
INSPECT PER ST0901LT0007 CLASS I

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON DECIMALS .XX = ±.03 .XXX = ±.010 ANGLES ±0°30'
DO NOT SCALE PRINT
DIMENSIONS AND TOLERANCES PER ANSI Y14.5

DWN BY
CHK BY
ENGR

Rockwell International Corporation
B-1 Division
INTERNATIONAL AIRPORT LOS ANGELES, CALIFORNIA 90009

FITTING-INBD ATTACH WING SWEEP ACTUATOR, ASSY OF

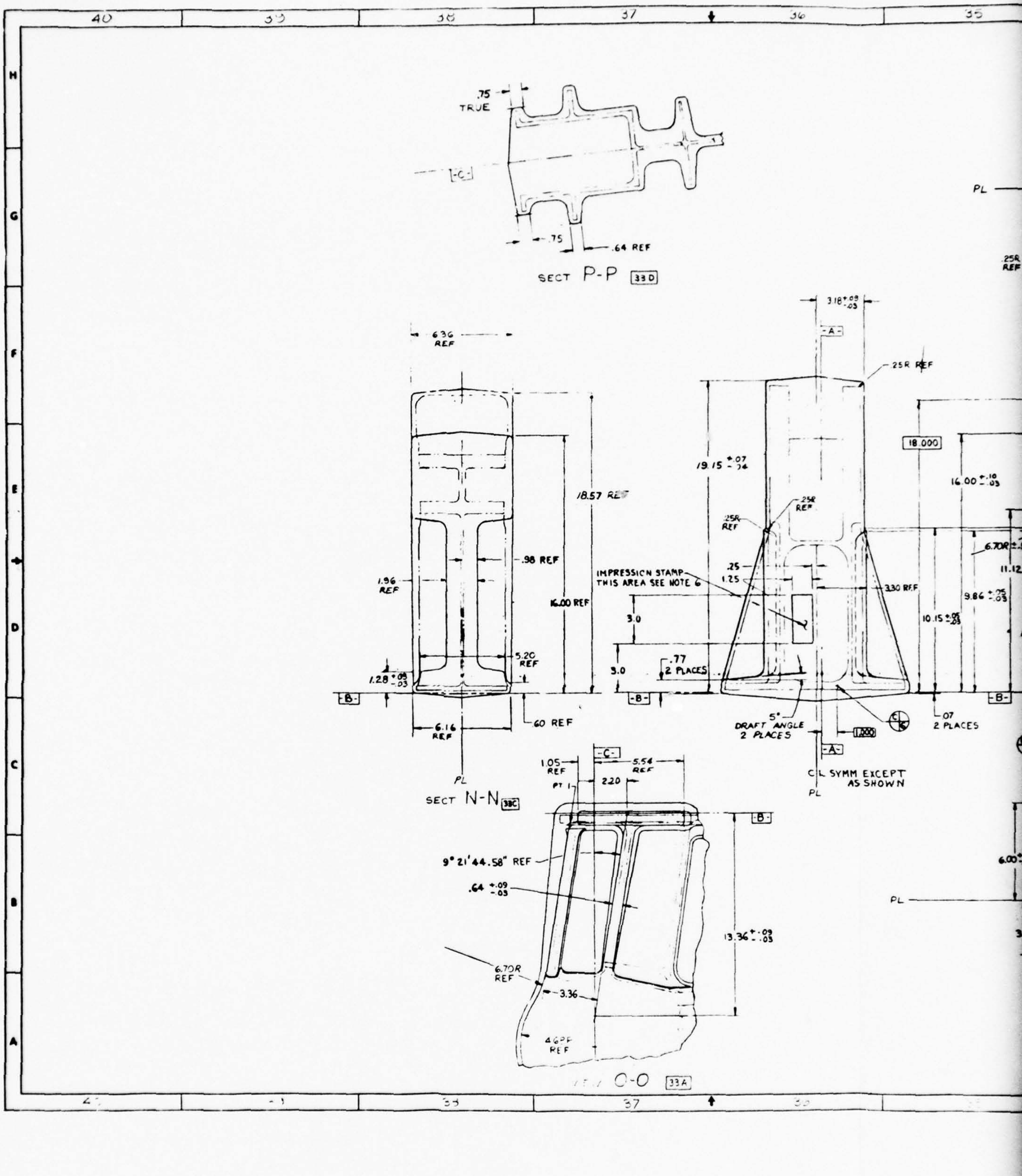
SIZE J | CODE IDENT 43999 | DRAWING NO 3109-100006

3109-100006

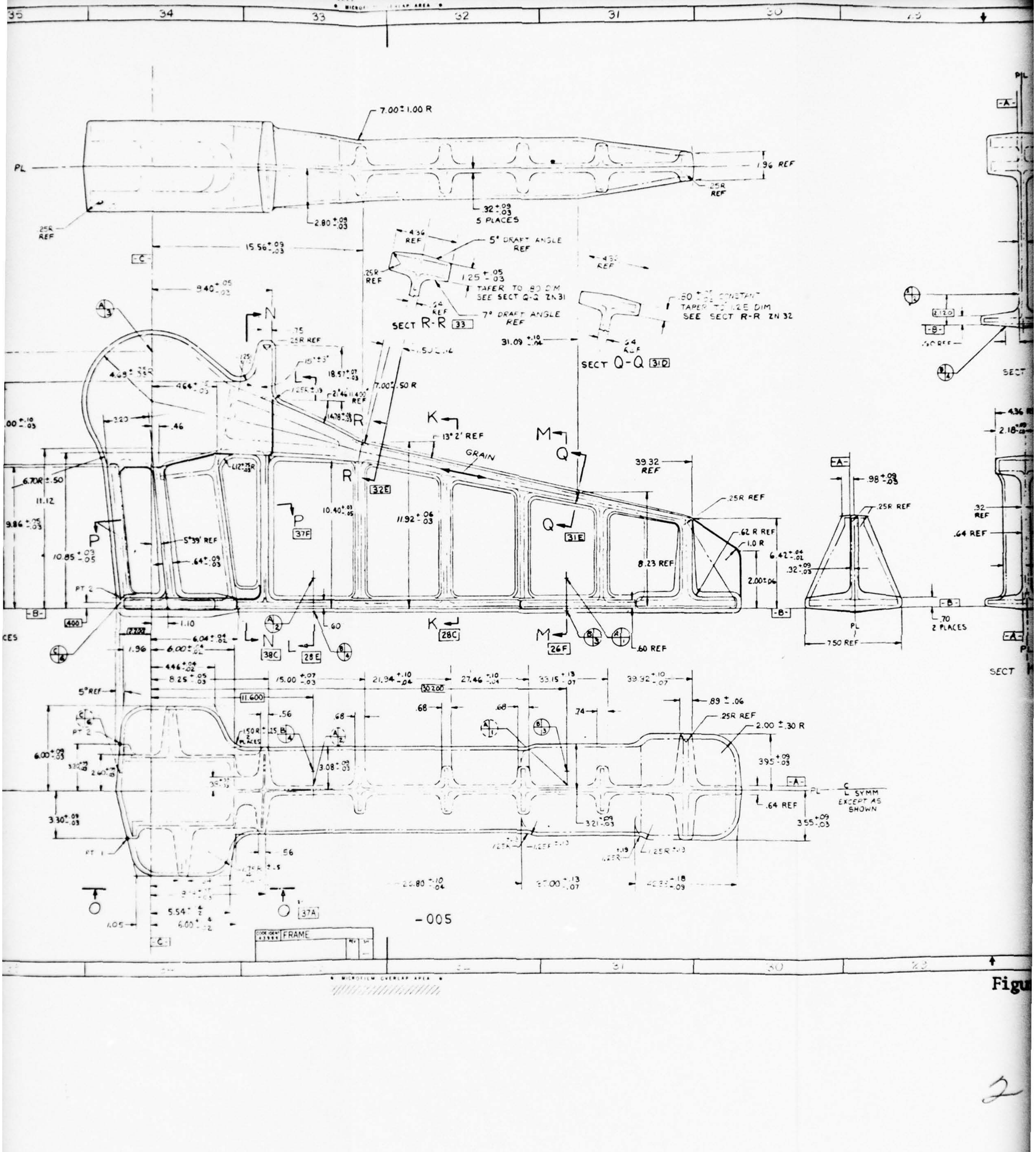
Figure A-2, 3109-100006 Fitting-Inboard Attachment, Wing Sweep Actuator, Assembly

3

4



40
39
38
37
36
35
H
G
F
E
D
C
B
A
.75
TRUE
-C-
.75
.64 REF
SECT P-P 33D
PL
.25R
REF
3.18 +.09 -.03
-A-
6.36
REF
.25R REF
18.000
19.15 +.07 -.04
16.00 +.10 -.03
18.57 REF
.25R
REF
.25R
REF
6.70R
11.12
.98 REF
IMPRESSION STAMP
THIS AREA SEE NOTE 6
.25
1.25
3.30 REF
1.96
REF
9.86 +.05 -.03
16.00 REF
3.0
10.15 +.05 -.03
5.20
REF
.77
2 PLACES
3.0
1.28 +.09 -.03
-B-
-B-
-B-
5°
DRAFT ANGLE
2 PLACES
.07
2 PLACES
1.200
-A-
6.16
REF
60 REF
-C-
1.05
REF
5.54
REF
PT 1
2.20
C L SYMM EXCEPT
AS SHOWN
PL
PL
SECT N-N 38C
-B-
9° 21' 44.58" REF
6.00
.64 +.09 -.03
PL
13.36 +.09 -.03
6.70R
REF
3.36
4.6RF
REF
O-O 33A
37


FRAME
-005
SECT R-R
SECT Q-Q
GRAIN
PL
SYMM EXCEPT AS SHOWN
5° DRAFT ANGLE REF
7° DRAFT ANGLE REF
TAPER TO .80 DIM SEE SECT Q-Q ZN31
TAPER TO 1.25 DIM SEE SECT R-R ZN 32
5 PLACES
7.00 ± 1.00 R
1.96 REF
39.32 REF
8.23 REF
7.50 REF

Figu

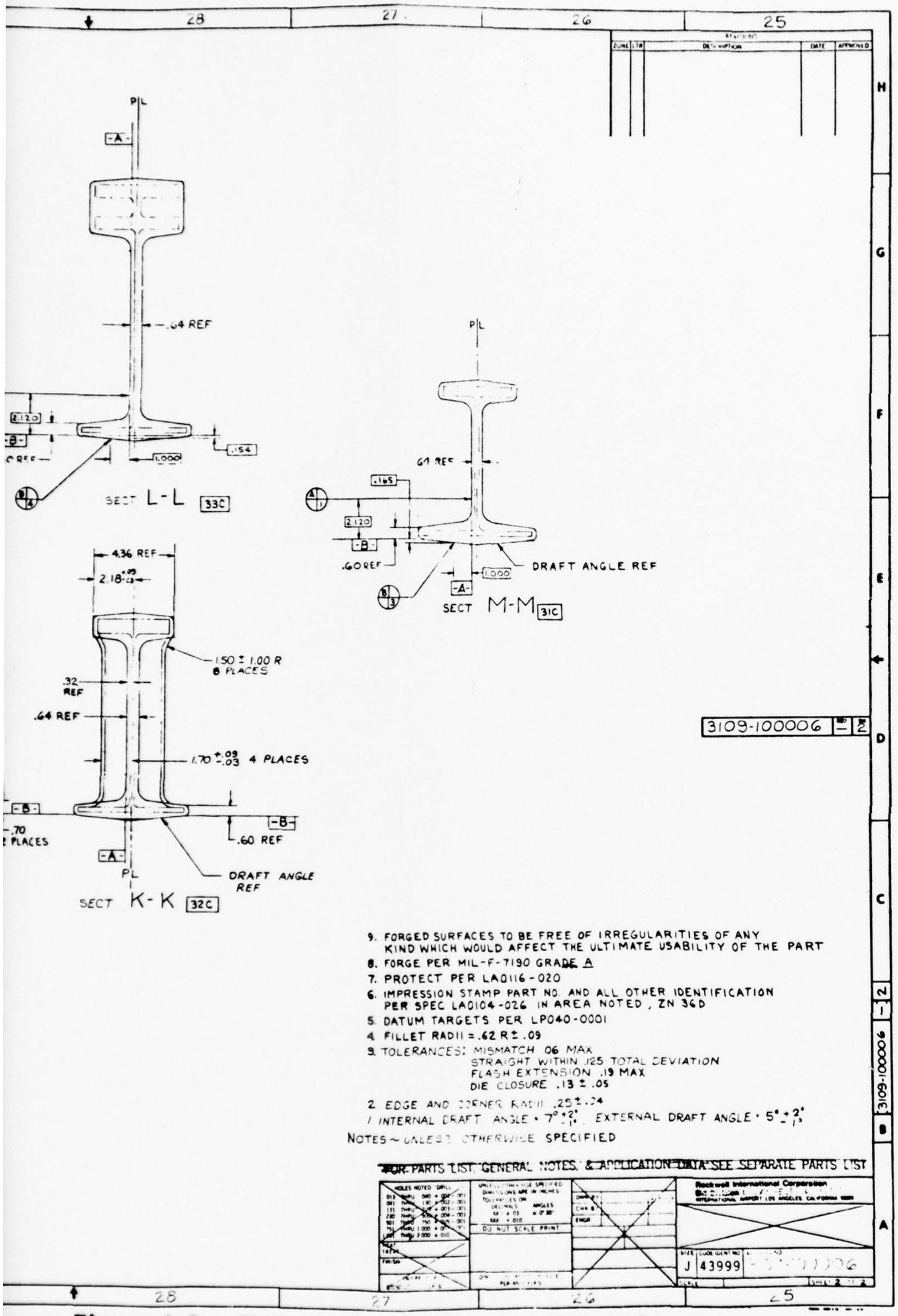


Figure A-2. 3109-100006 Fitting-Inboard Attachment, Wing Sweep Actuator, Assembly (Concluded)

2

3

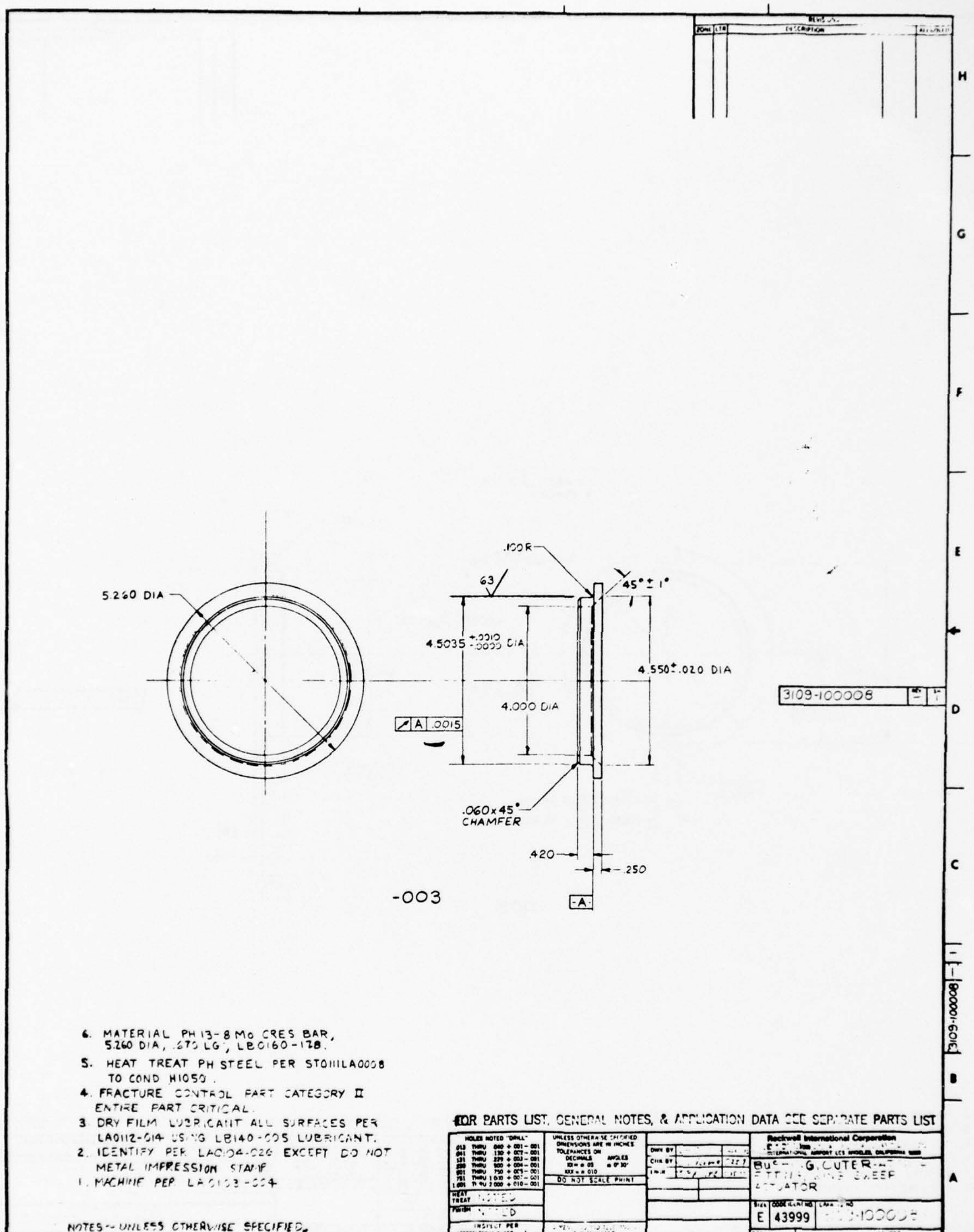


Figure A-3. Bushing, Outer - Attach Fitting, Wing Sweep Actuator

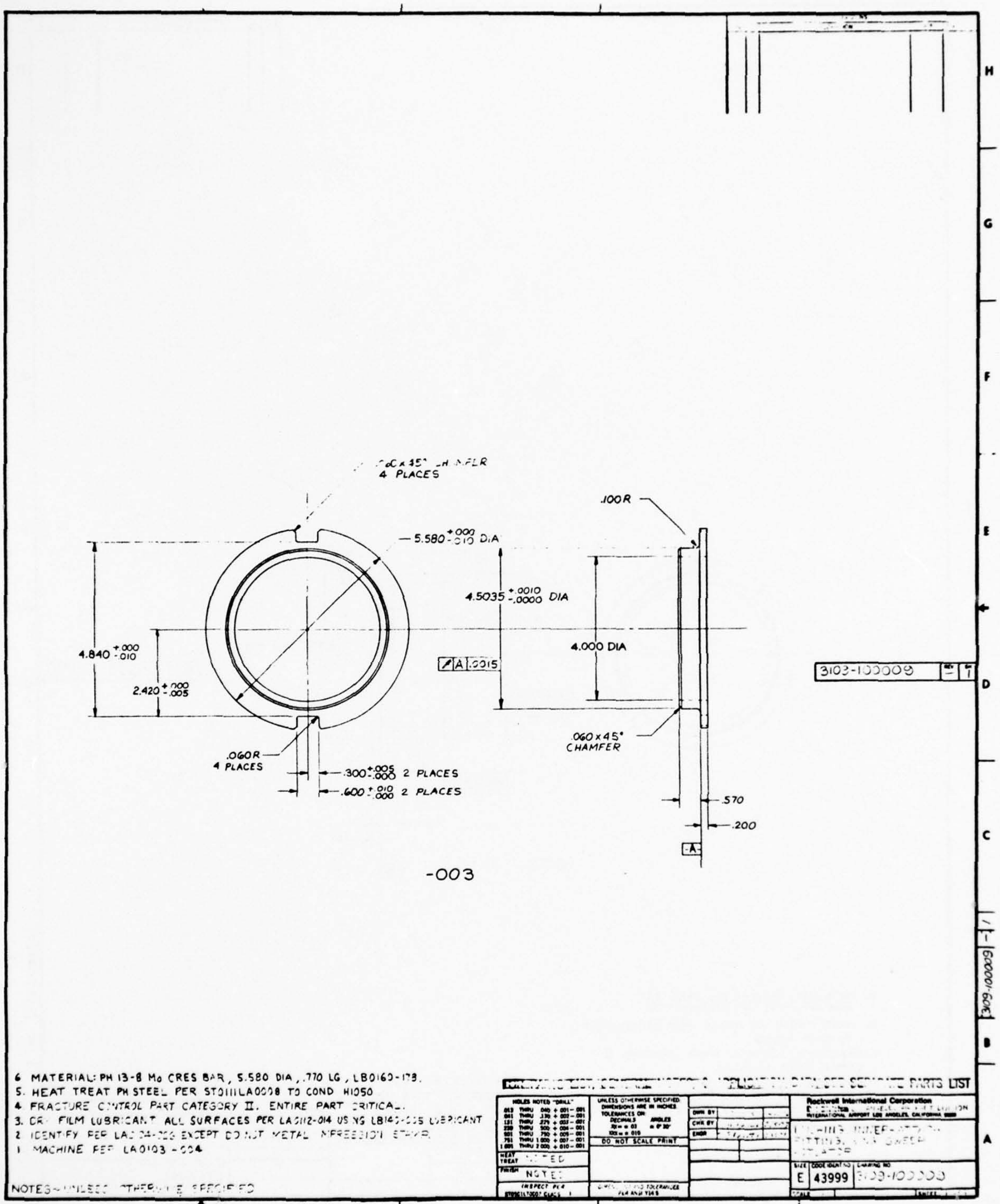


Figure.A-4 Bushing, Inner - Attach Fitting, Wing Sweep Actuator

APPENDIX B

AF1410 STEEL STRUCTURAL ANALYSIS
MATERIAL PROPERTIES

Table B-1

MATERIAL PROPERTIES - AF1410 STEEL

Heat-Treated Condition	Parent Metal	Welds Loaded in Shear or Transverse
F_{tu} (ksi)	230	196
F_{ty} (ksi)	215	183
F_{cy} (ksi)	226	192
F_{su} (ksi)	147	125
F_{bru} (ksi)	331 (e/D = 1.5)	
	446 (e/D = 2.0)	
F_{bry} (ksi)	301 (e/D = 1.5)	
	357 (e/D = 2.0)	
e (percent)	10	
E 10^6 psi	28.0	28.0
E_c 10^6 psi	28.0	28.0
G 10^6 psi	10.6	10.6
μ (in/in.)	0.32	0.32
w (pci)	0.285	0.285
K_{Ic} (ksi $\sqrt{\text{in.}}$)	130	

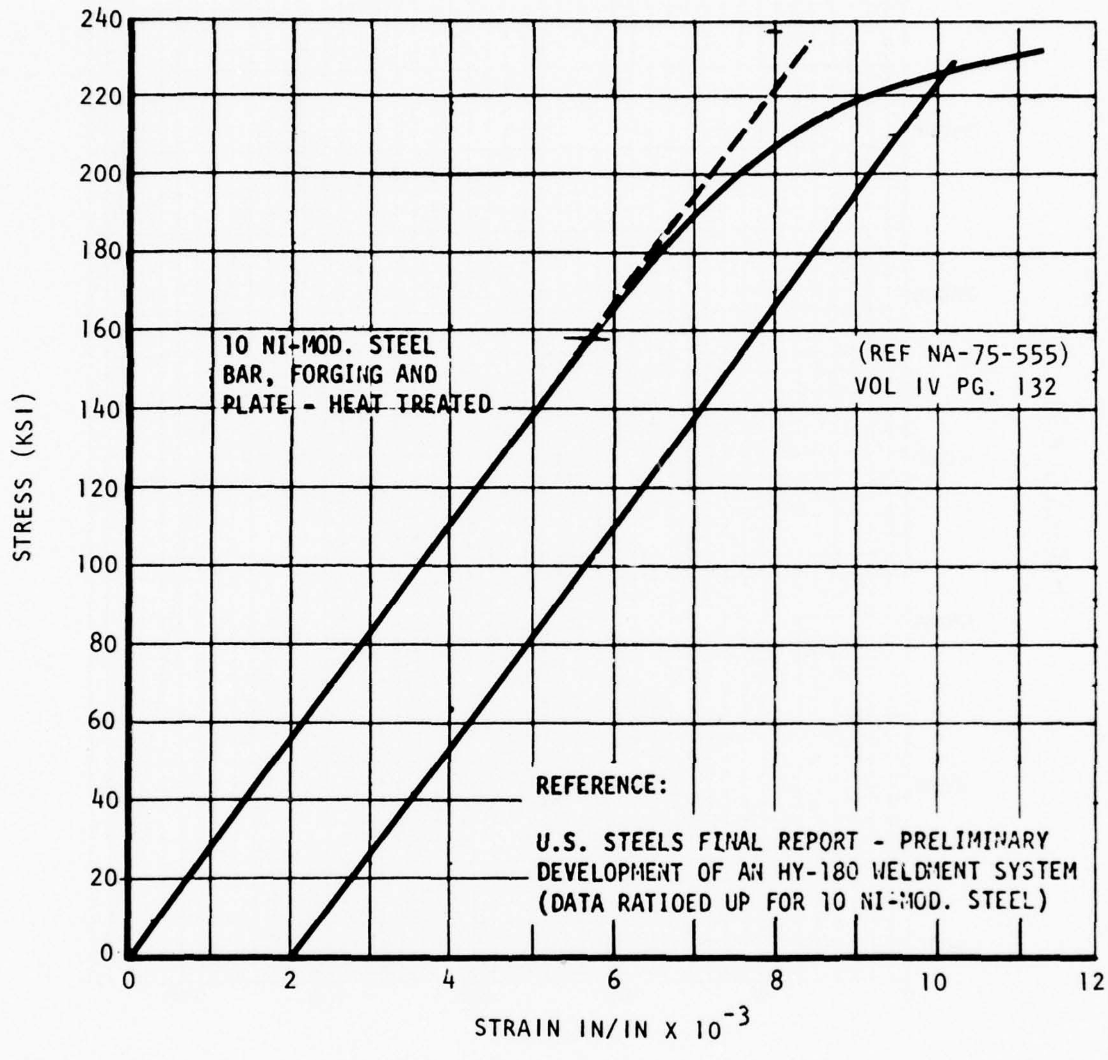


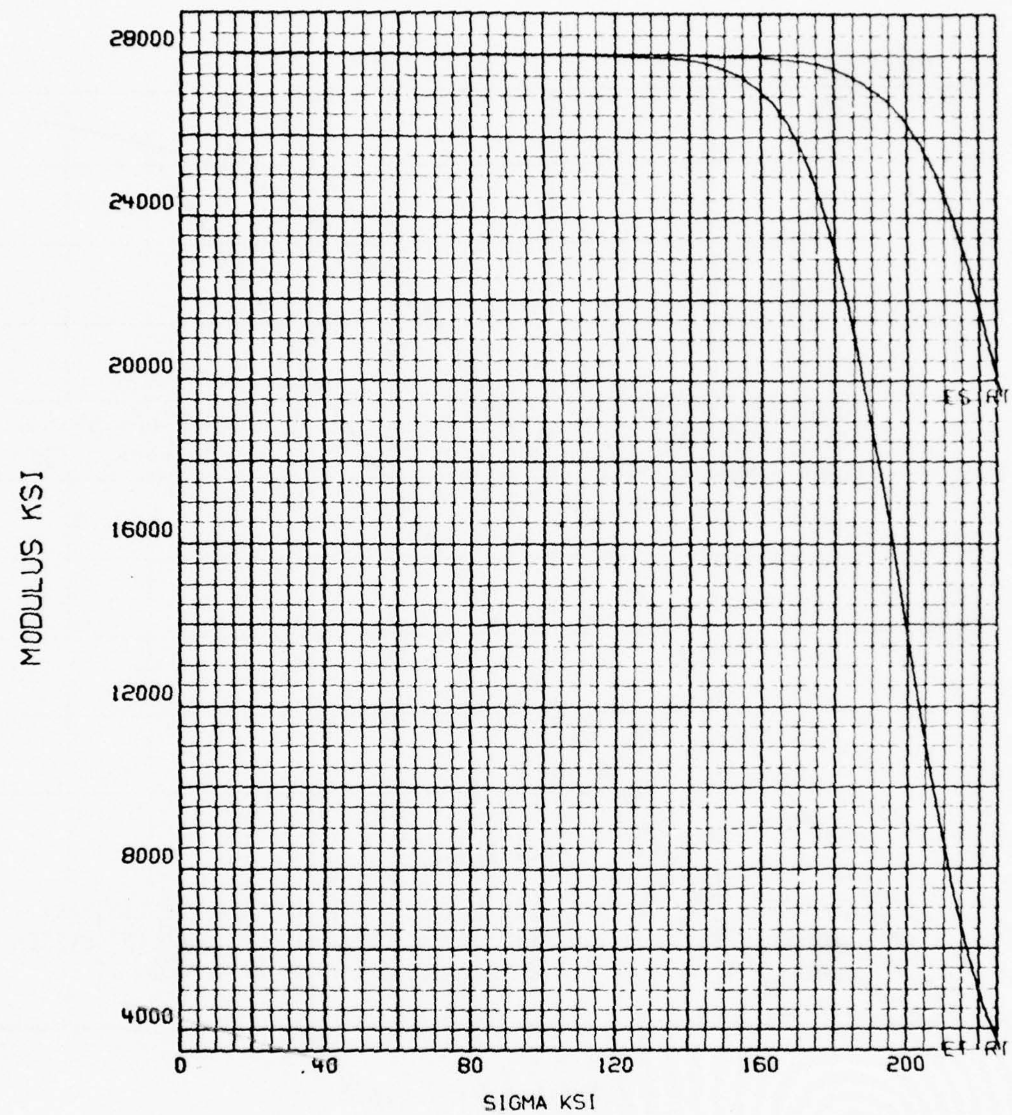
Figure B-1. AF1410 Steel - Room Temperature Compressive Stress-Strain Curve

TANGENT AND SECANT MODULUS CURVES

AF1410 ALLOY STEEL BAR,FORGINGS,AND PLATE HEAT TREATED TO 230 KSI

PRELIMINARY DESIGN PROPERTIES

TEMPERATURE= RT   FCY=226 KSI   E=28 MSI   FSU 147 KSI   N=16.5



AF1410 ALLOY STEEL

Figure B-2. Tangent and Secant Modulus Curves

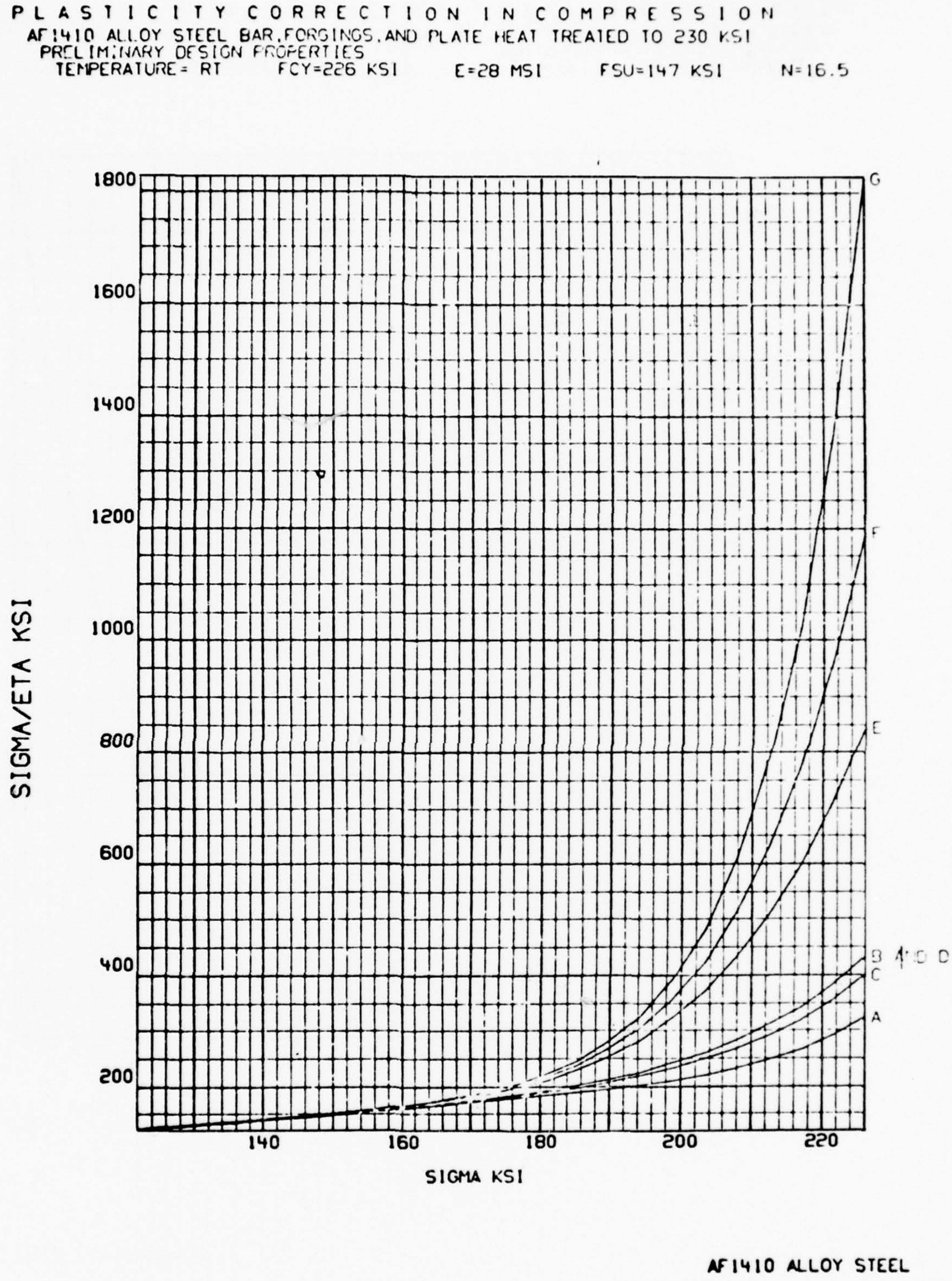


Figure B-3 Plasticity Correction in Compression

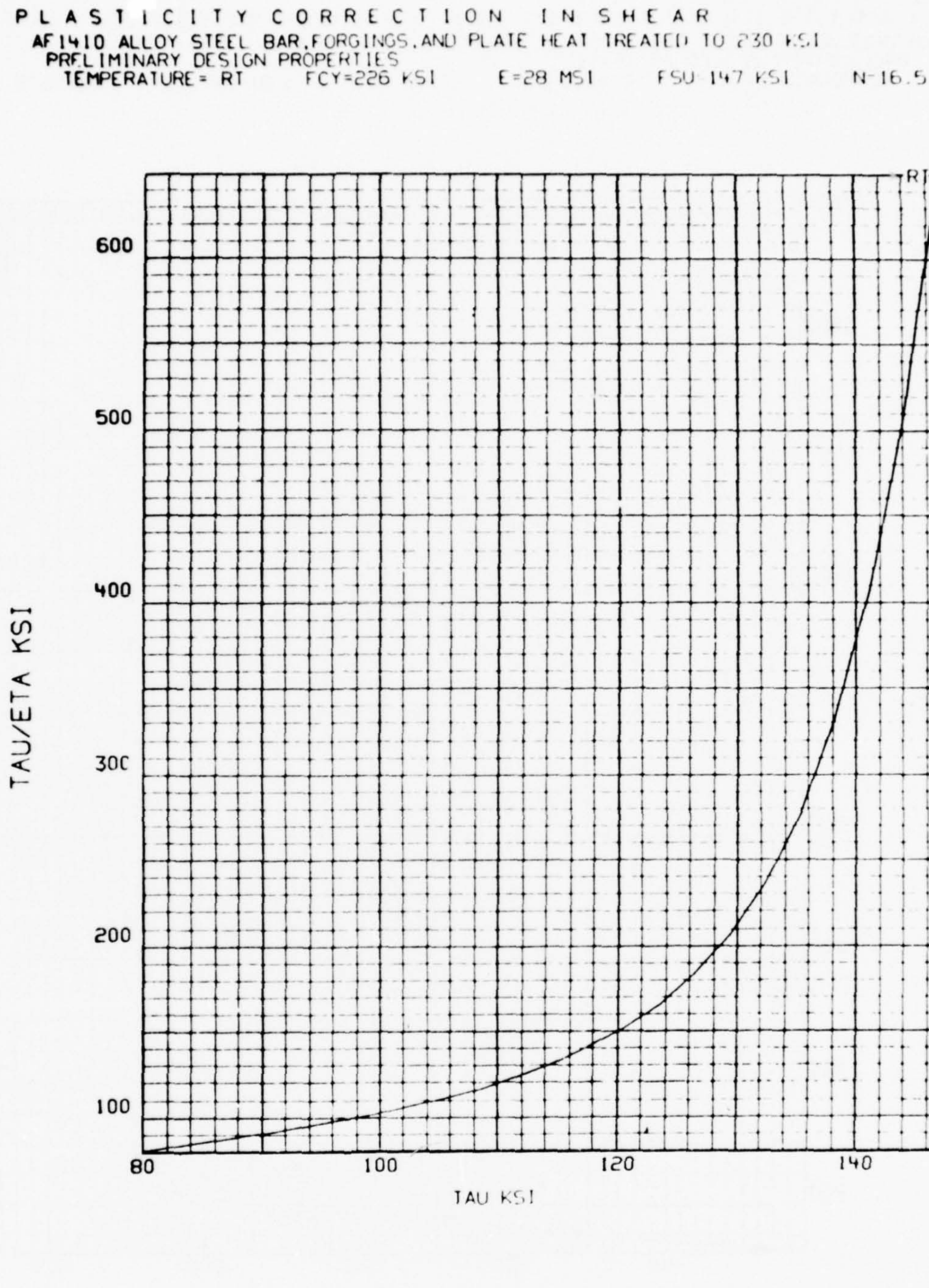
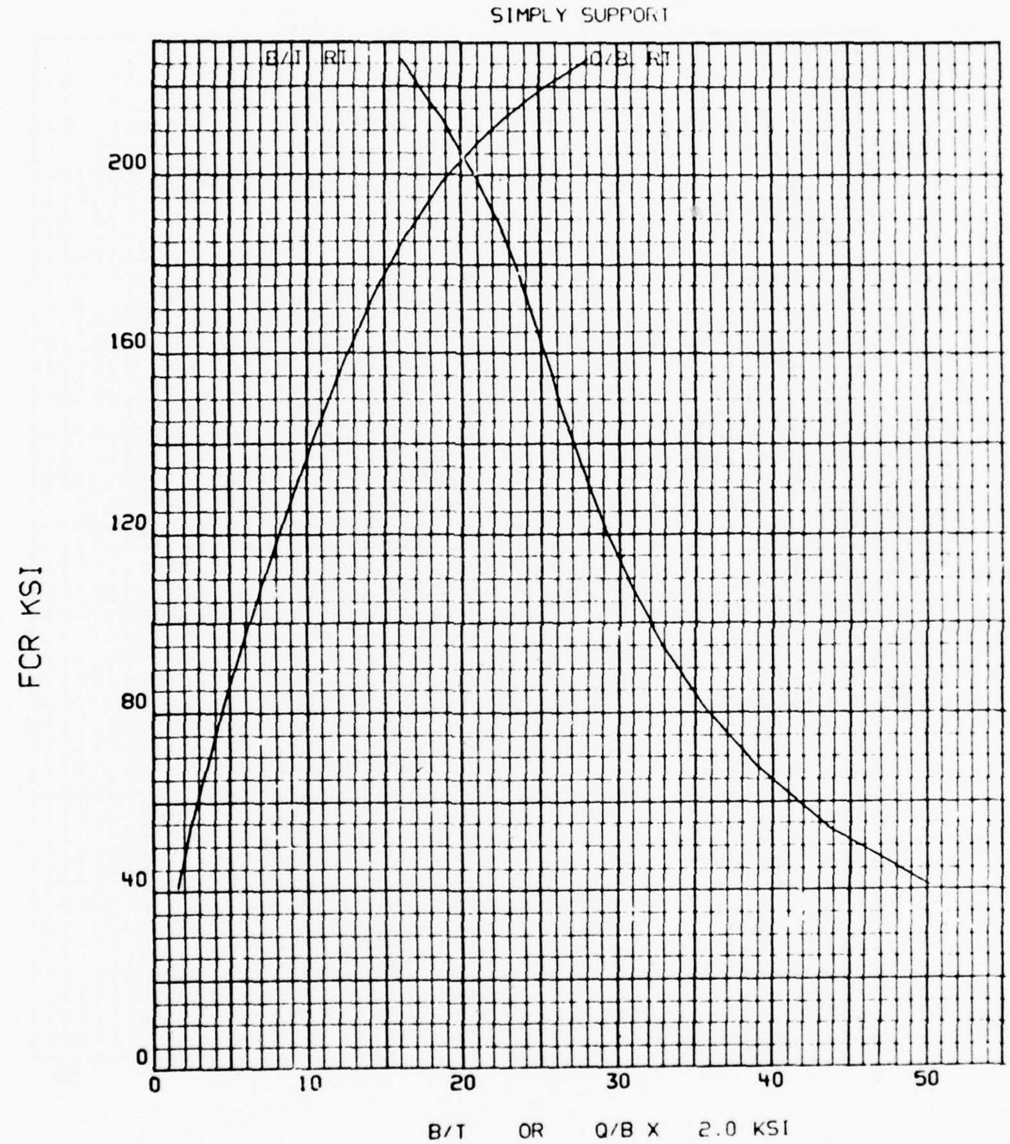


Figure B-4. Plasticity Correction in Shear

COMPRESSION BUCKLING STRESS

AF1410 ALLOY STEEL BAR,FORGINGS,AND PLATE HEAT TREATED TO 230 KSI
PRELIMINARY DESIGN PROPERTIES
TEMPERATURE= RT FCY=226 KSI E=28 MSI FSU=147 KSI N=16.5

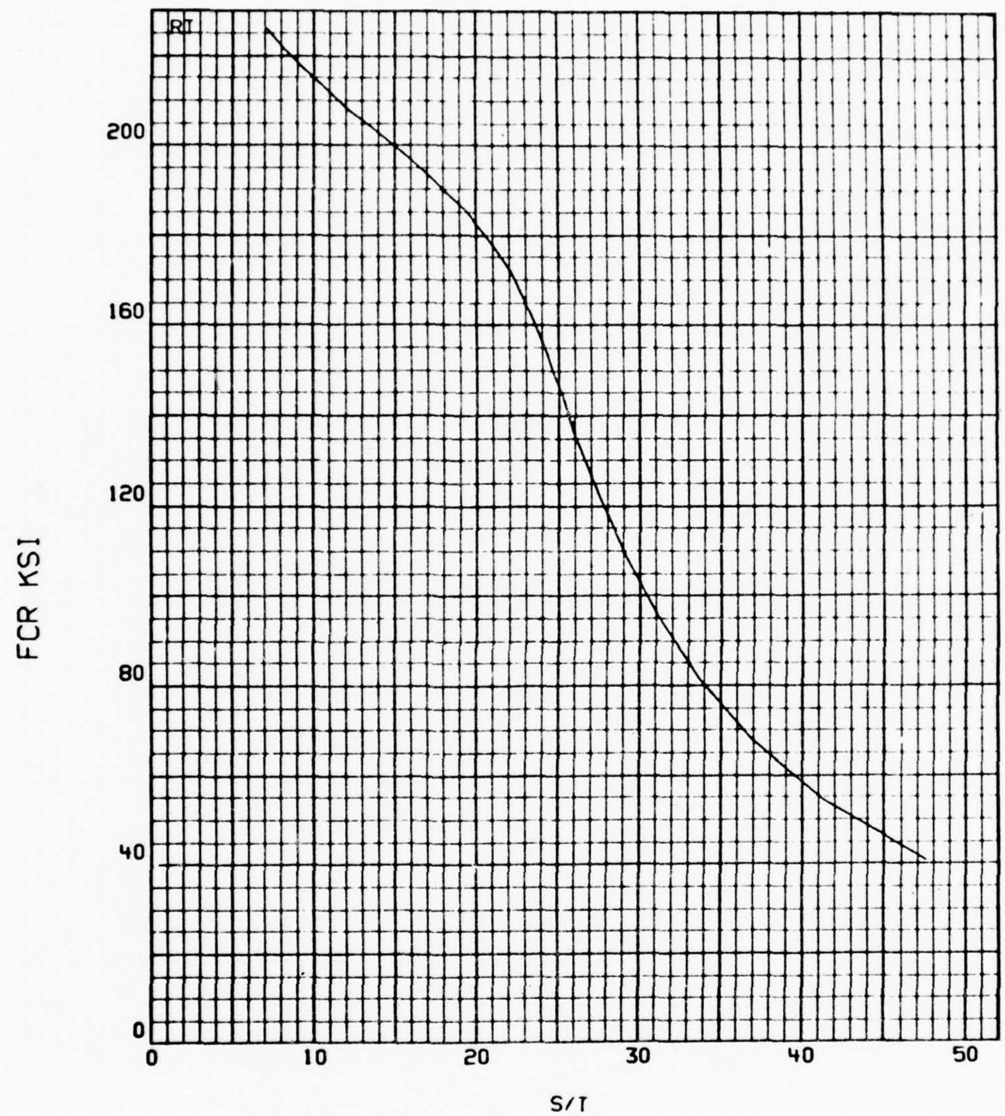


AF1410 ALLOY STEEL

Figure B-5. Compression Buckling Stress

INTER-RIVET BUCKLING

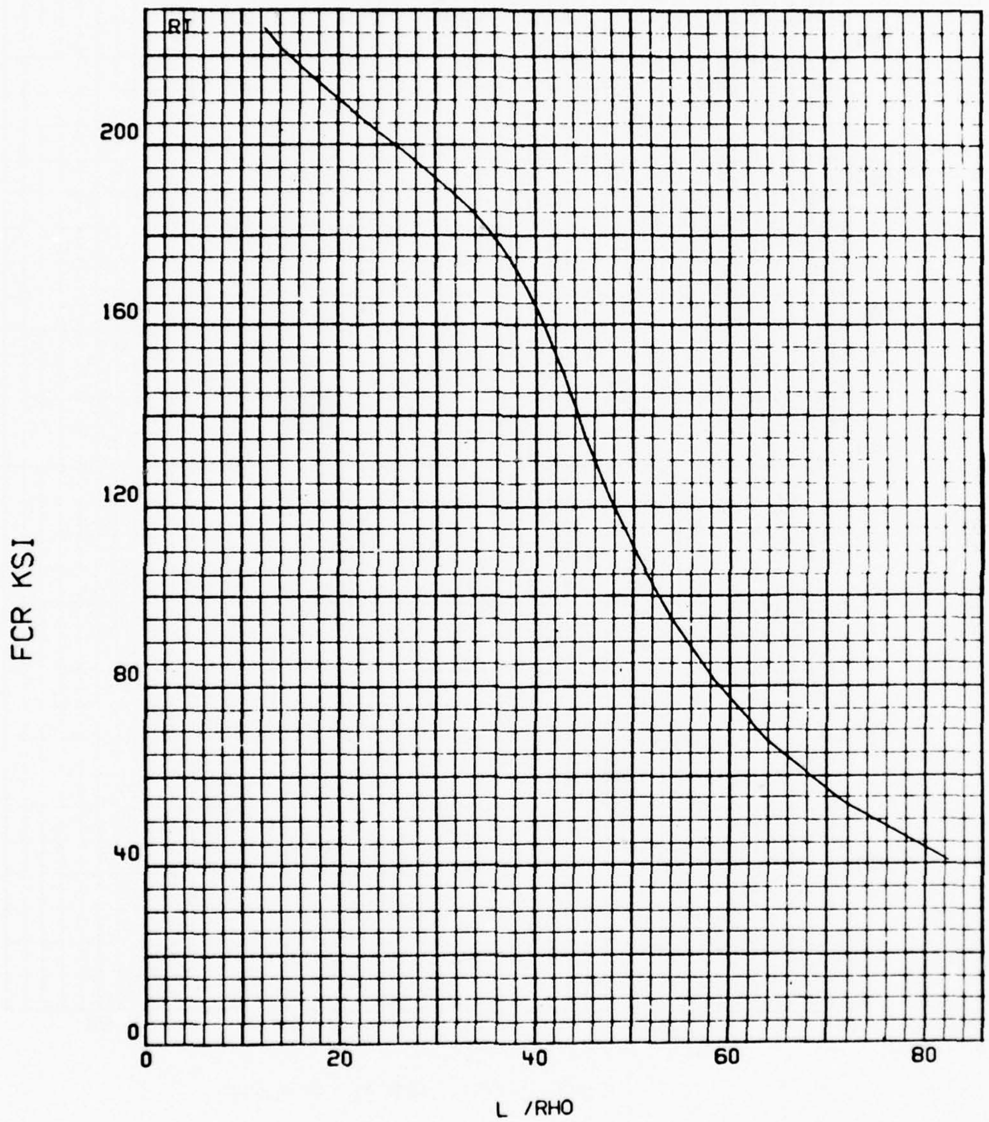
AF1410 ALLOY STEEL BAR, FORGINGS, AND PLATE HEAT TREATED TO 230 KSI
PRELIMINARY DESIGN PROPERTIES
TEMPERATURE= RT   FCY=226 KSI   E=28 MSI   FSU=147 KSI   N=16.5



AF1410 ALLOY STEEL

Figure B-6. Allowable Column Stresses

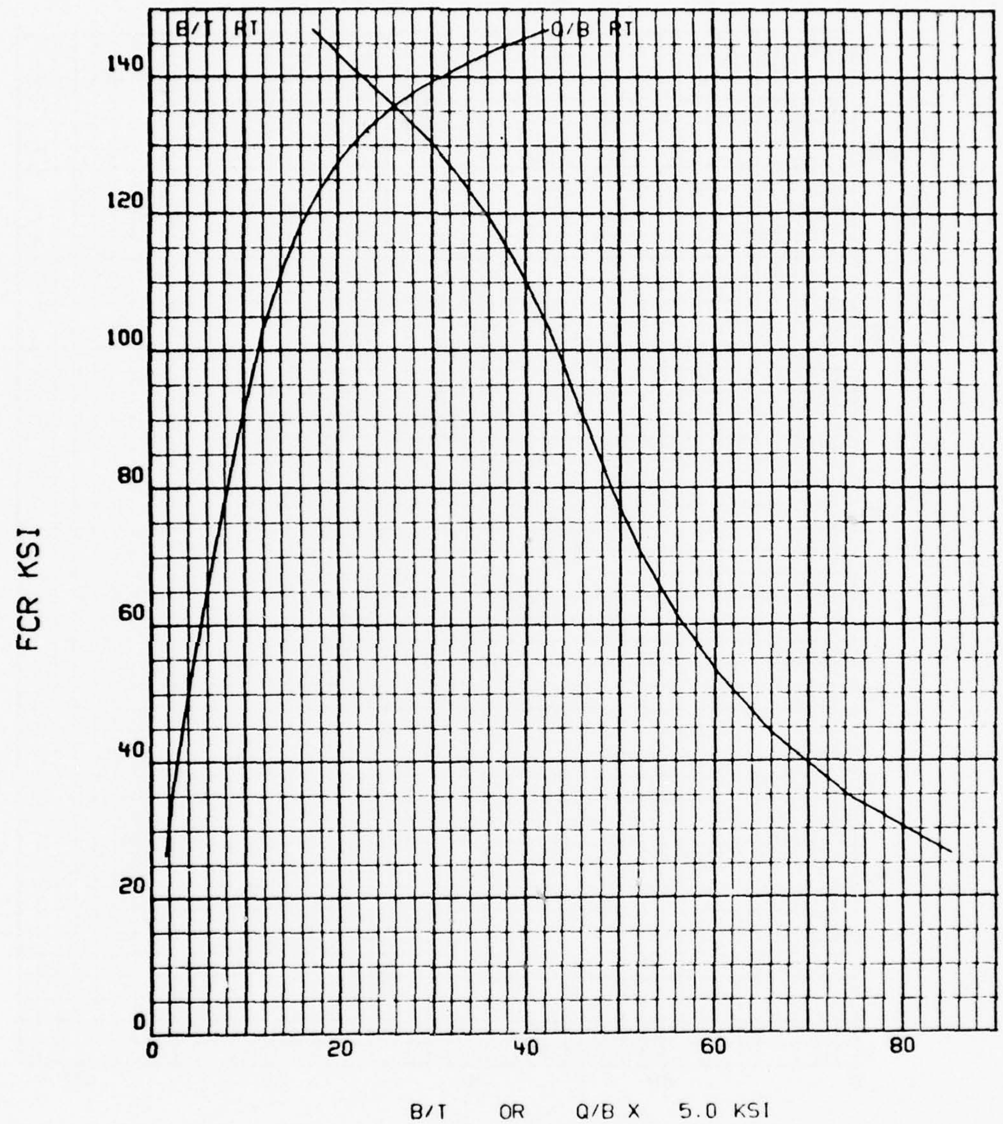
ALLOWABLE COLUMN STRESSES
AF1410 ALLOY STEEL BAR,FORGINGS,AND PLATE HEAT TREATED TO 230 KSI
PRELIMINARY DESIGN PROPERTIES
TEMPERATURE= RT FCY=226 KSI E=28 MSI FSU=147 KSI N=16.5



AF1410 ALLOY STEEL

Figure B-7. Interrivet Buckling

SHEAR BUCKLING STRESS
AF1410 ALLOY STEEL BAR,FORGINGS,AND PLATE HEAT TREATED TO 230 KSI
PRELIMINARY DESIGN PROPERTIES
TEMPERATURE= RT FCY=226 KSI E=28 MSI FSU=147 KSI N=16.5



AF1410 ALLOY STEEL

Figure B-8. Shear Buckling Stress AF1410 Alloy Steel

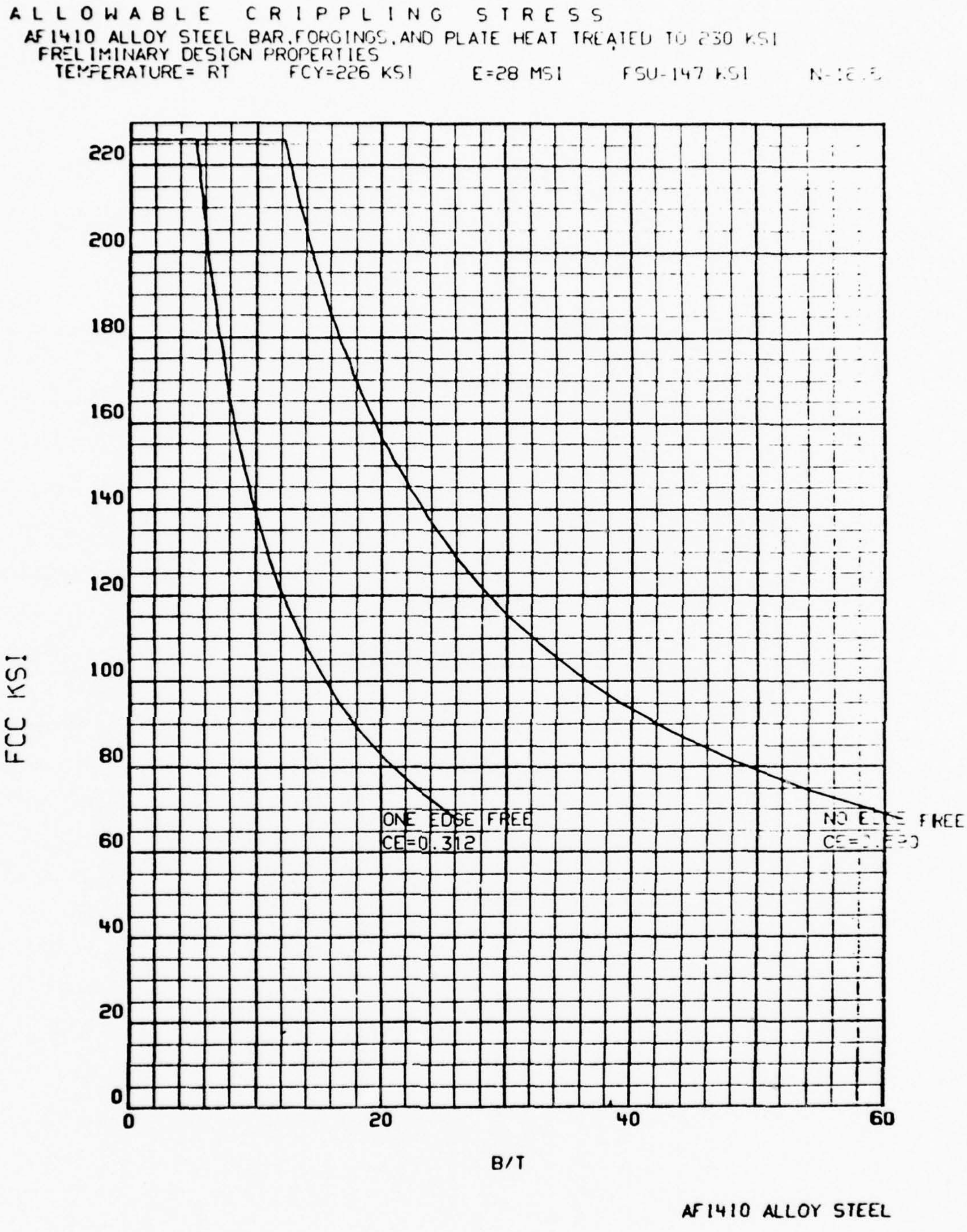


Figure B-9. Allowable Crippling Stress AF1410 Alloy Steel

APPENDIX C

TEST SPECIMEN DRAWINGS

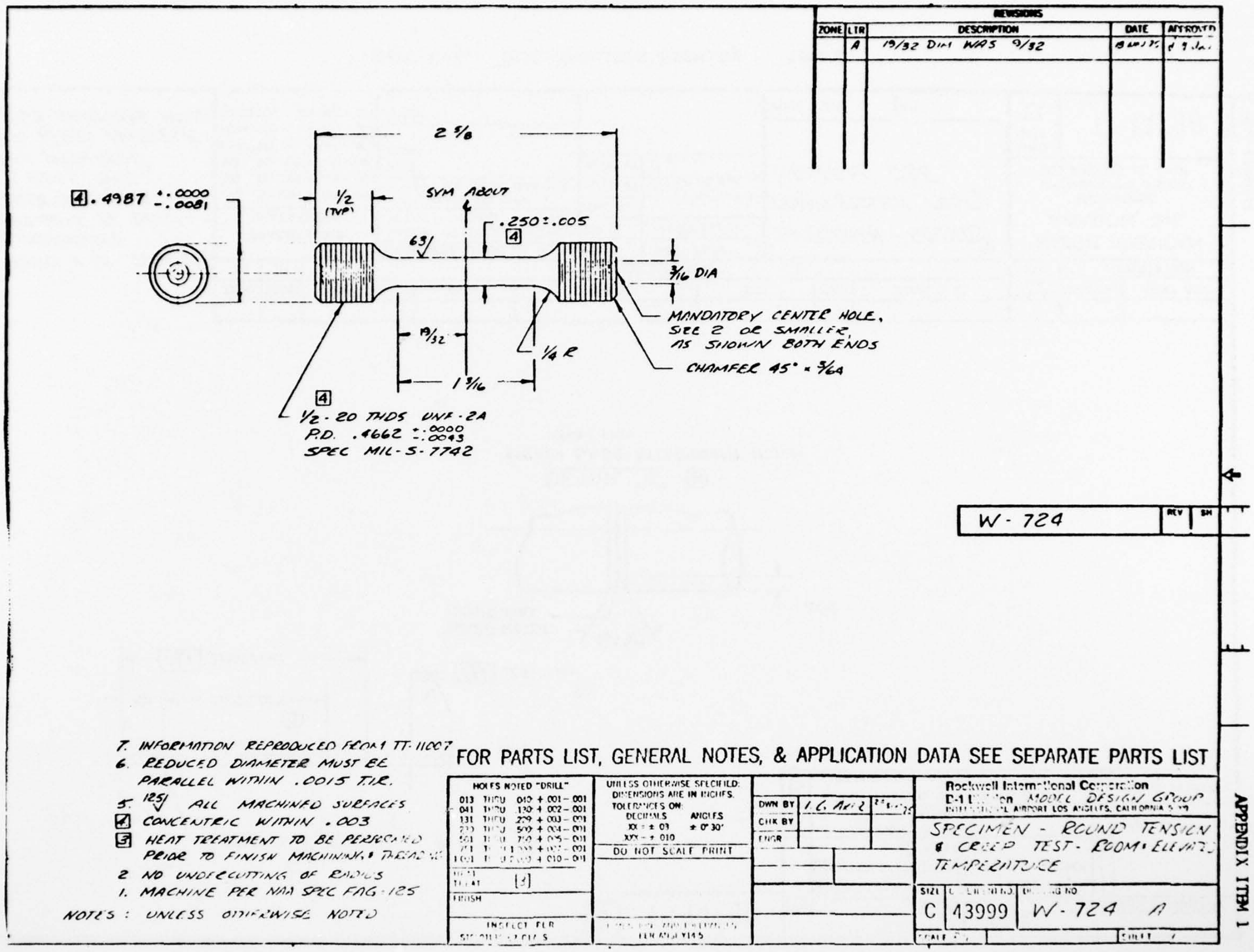


Figure C-1. Test Specimen Drawing - Item 1

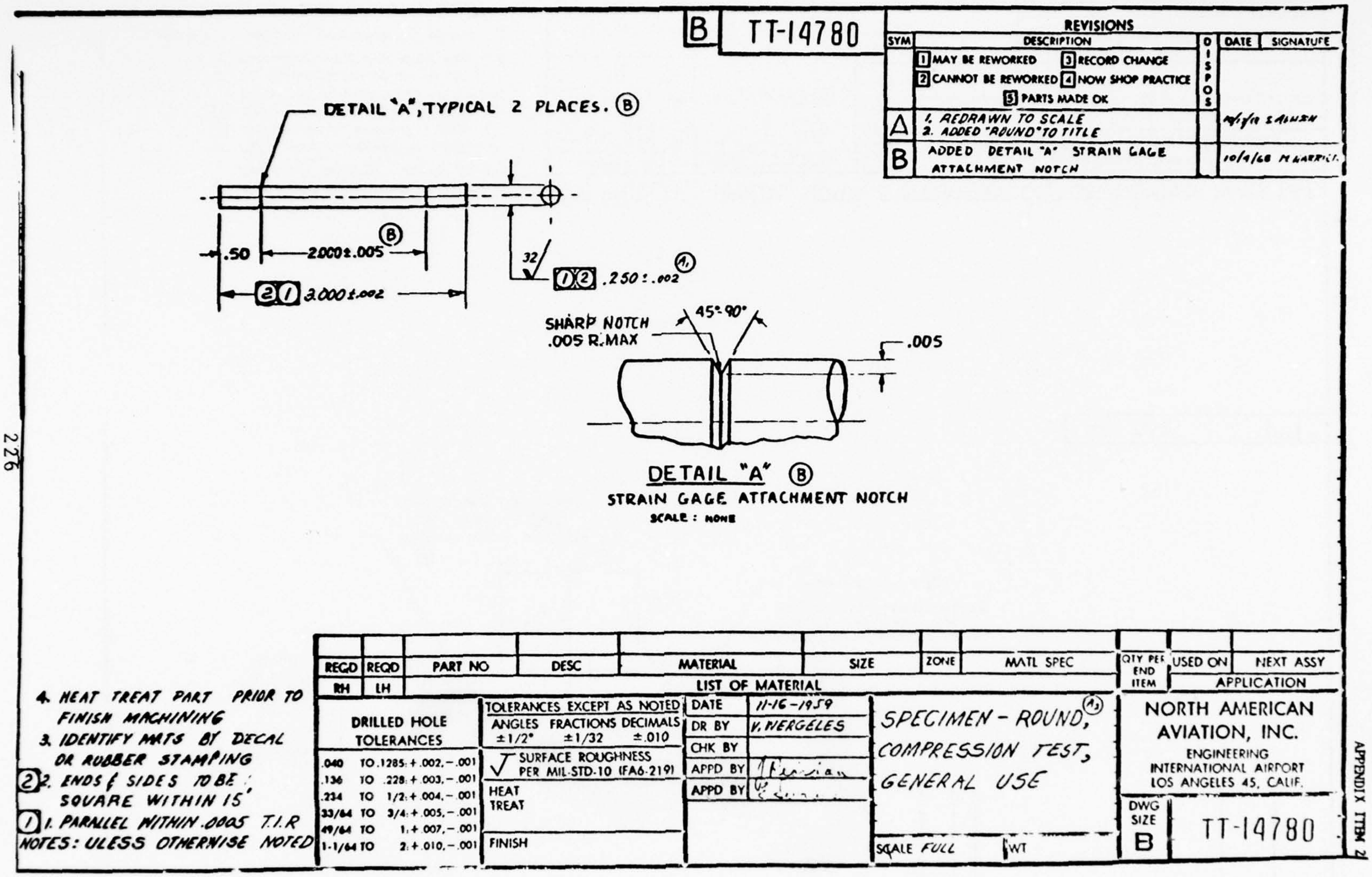


Figure C-2. Test Specimen Drawing - Item 2

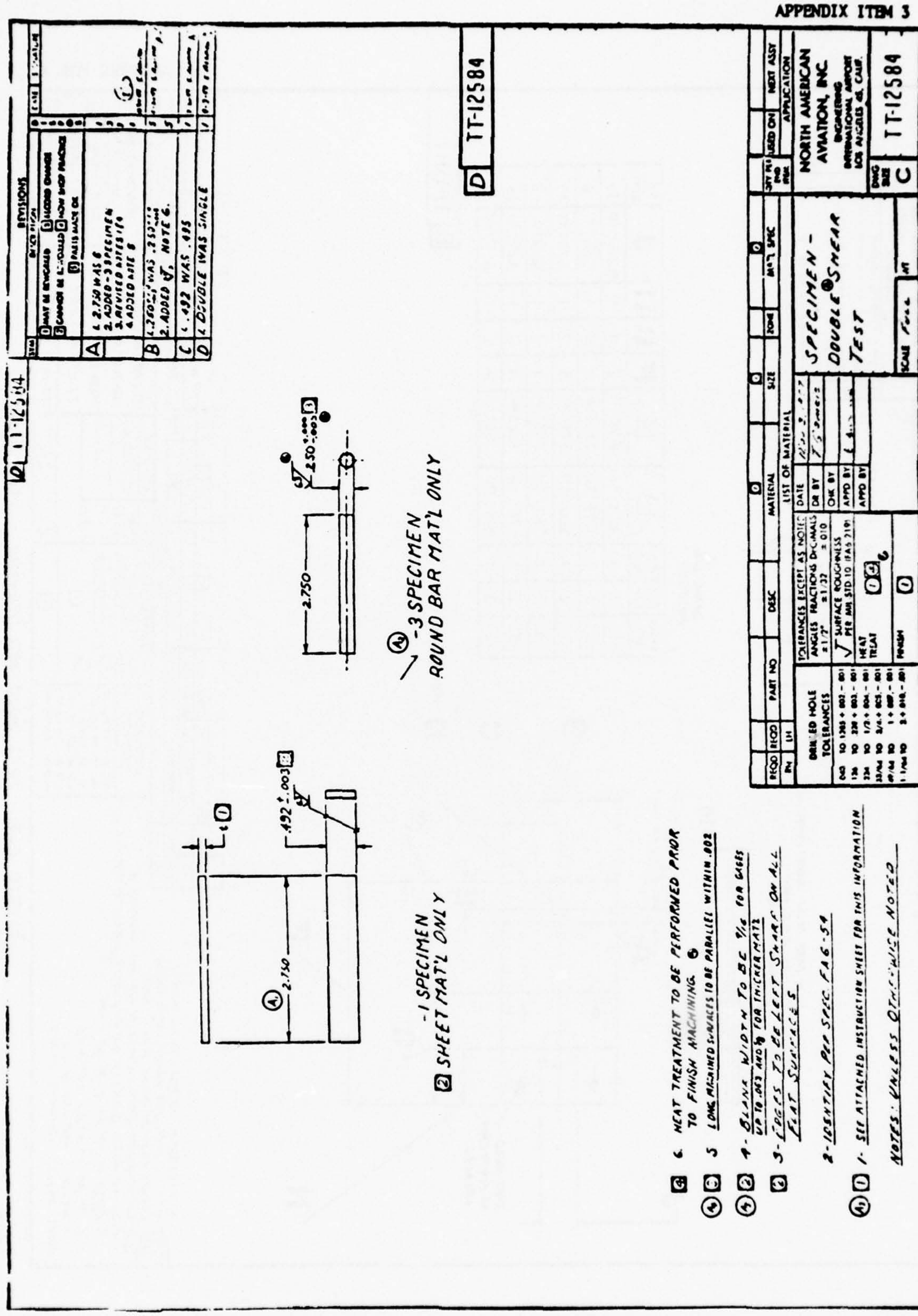


Figure C-3. Test Specimen Drawing - Item 3

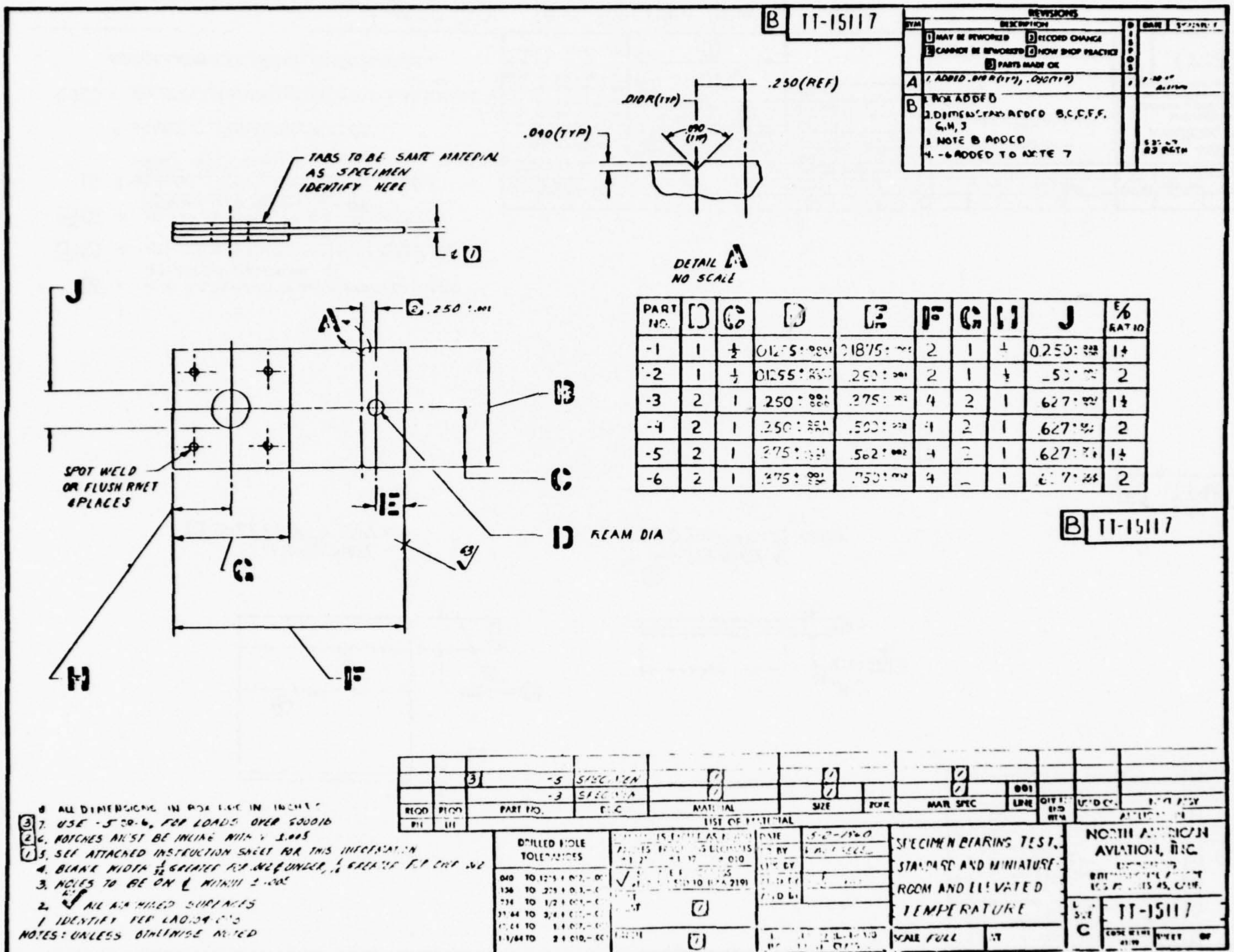


Figure C-4. Test Specimen Drawing - Item 4

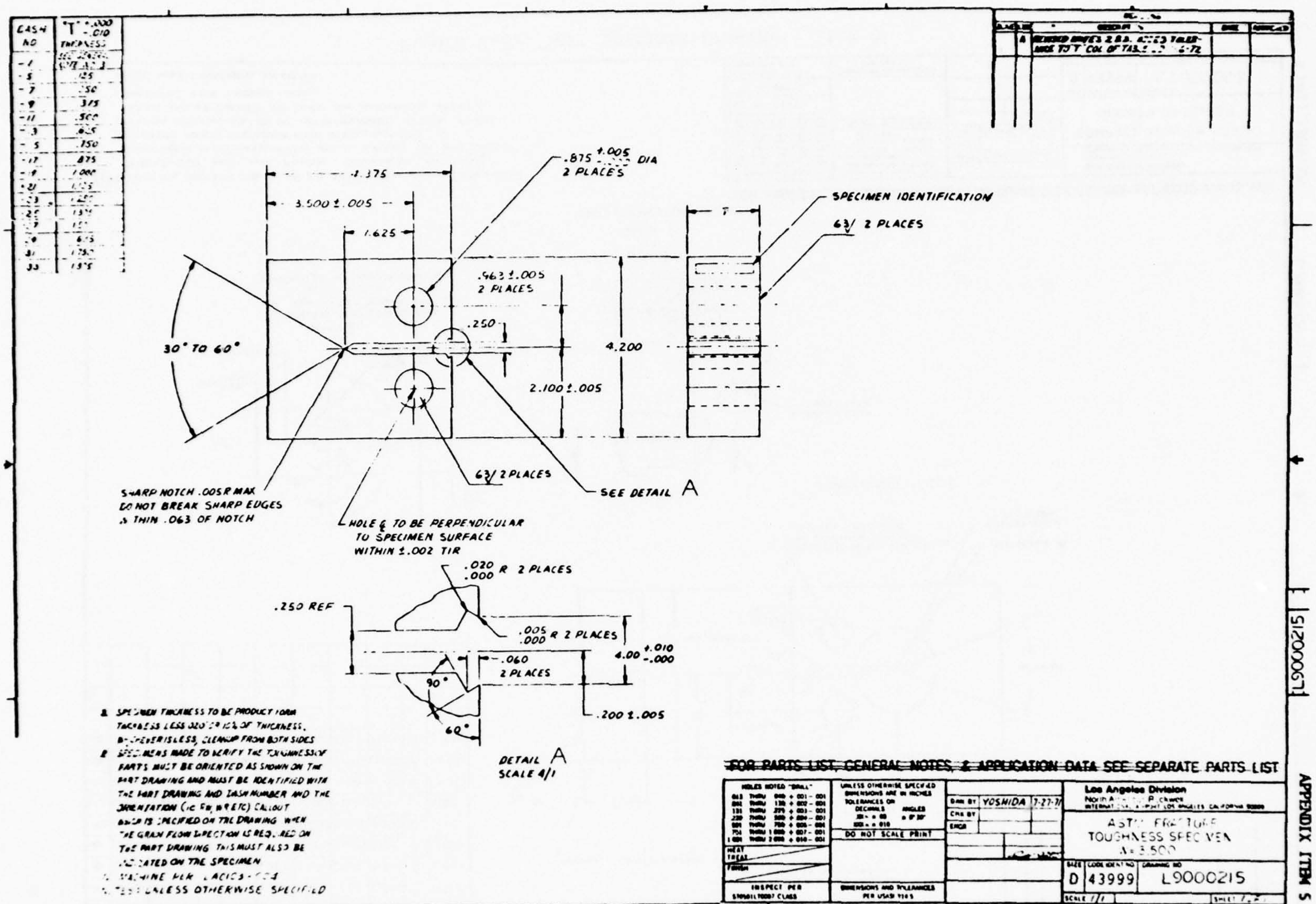


Figure C-5. Test Specimen Drawing - Item 5

DASH NO.	T (INCH) ① MIN.	T (INCH) ① MAX.	W ±.005	W_1 ±.010	H ±.005	2H ±.010	H_1 ±.005	D +.005 −.000	N	C ±.010 FATIGUE
-2	0.063	0.500	1.235	1.485	0.600	1.200	0.275	0.250	1/16	0.312
-4	0.100	0.750	1.850	2.255	0.900	1.800	0.415	0.375	1/16	0.500
-6	0.125	1.000	2.470	2.970	1.200	2.400	0.550	0.500	1/8	0.687
-8	0.1875	1.000	3.090	3.715	1.500	3.000	0.6875	0.625	1/8	0.825
-10	0.1875	1.000	3.770	4.520	1.800	3.600	0.825	0.750	1/4	1.000
-12	0.250	1.000	4.330	5.205	2.100	4.200	0.9625	0.875	1/4	1.187
-14	0.250	1.000	4.940	5.940	2.400	4.800	1.100	1.000	3/8	1.375
-16	0.3125	1.000	6.180	7.430	3.000	6.000	1.375	1.250	3/8	1.625
-18	0.250	1.000	7.400	8.900	3.600	7.200	1.650	1.500	3/8	2.000

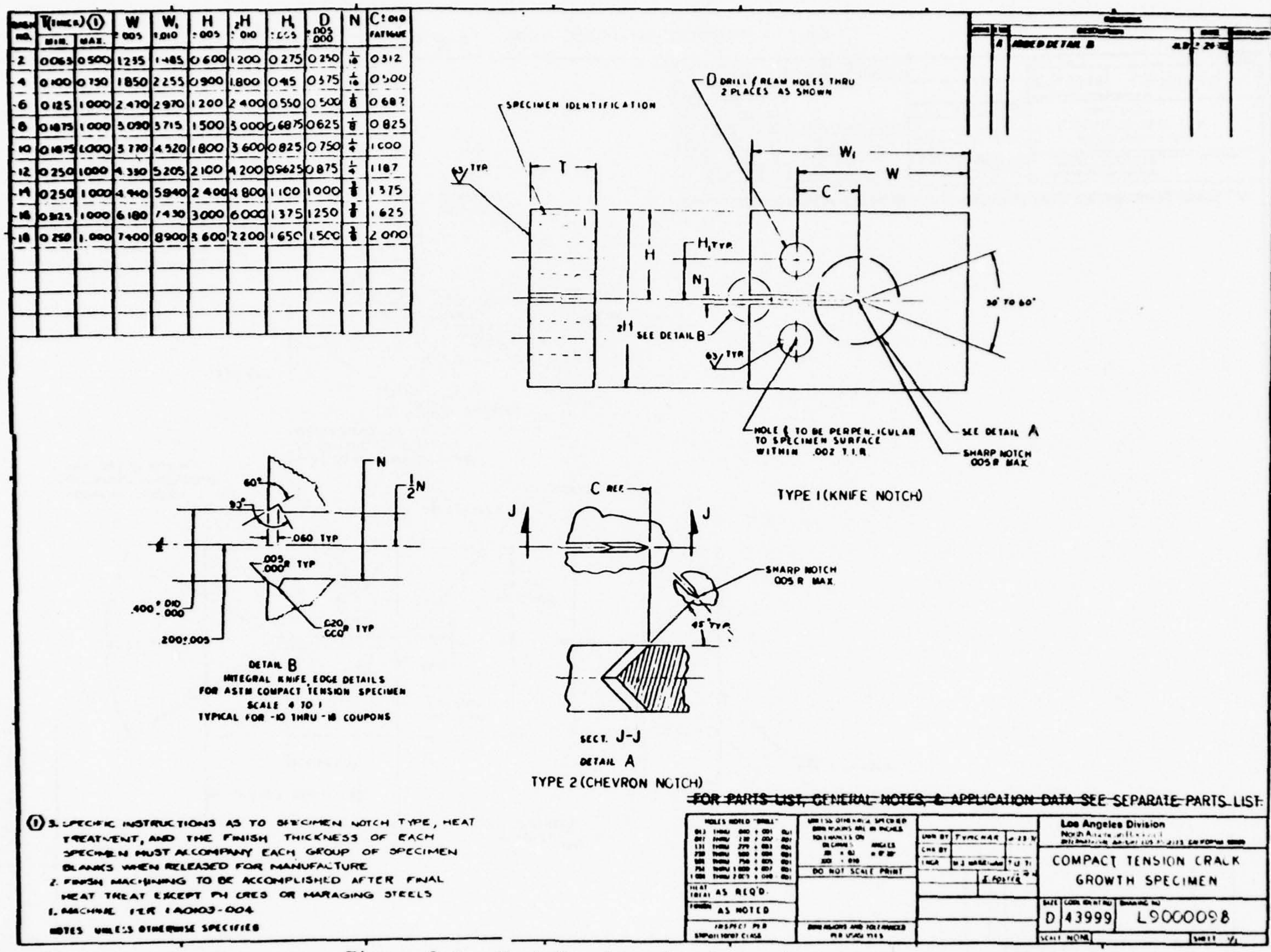


Figure C-6. Test Specimen Drawing - Item 6

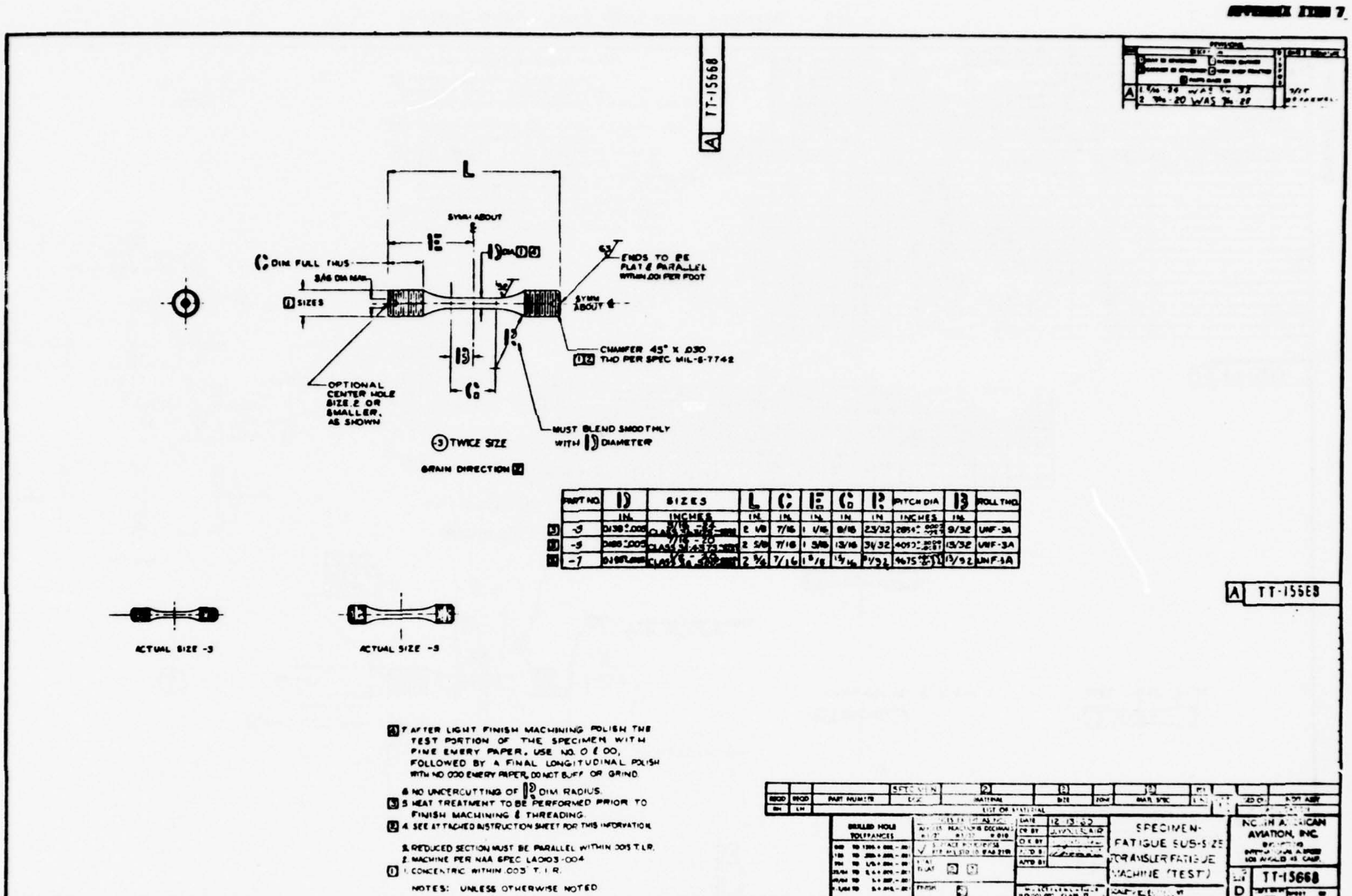


Figure C-7. Test Specimen Drawing - Item 7

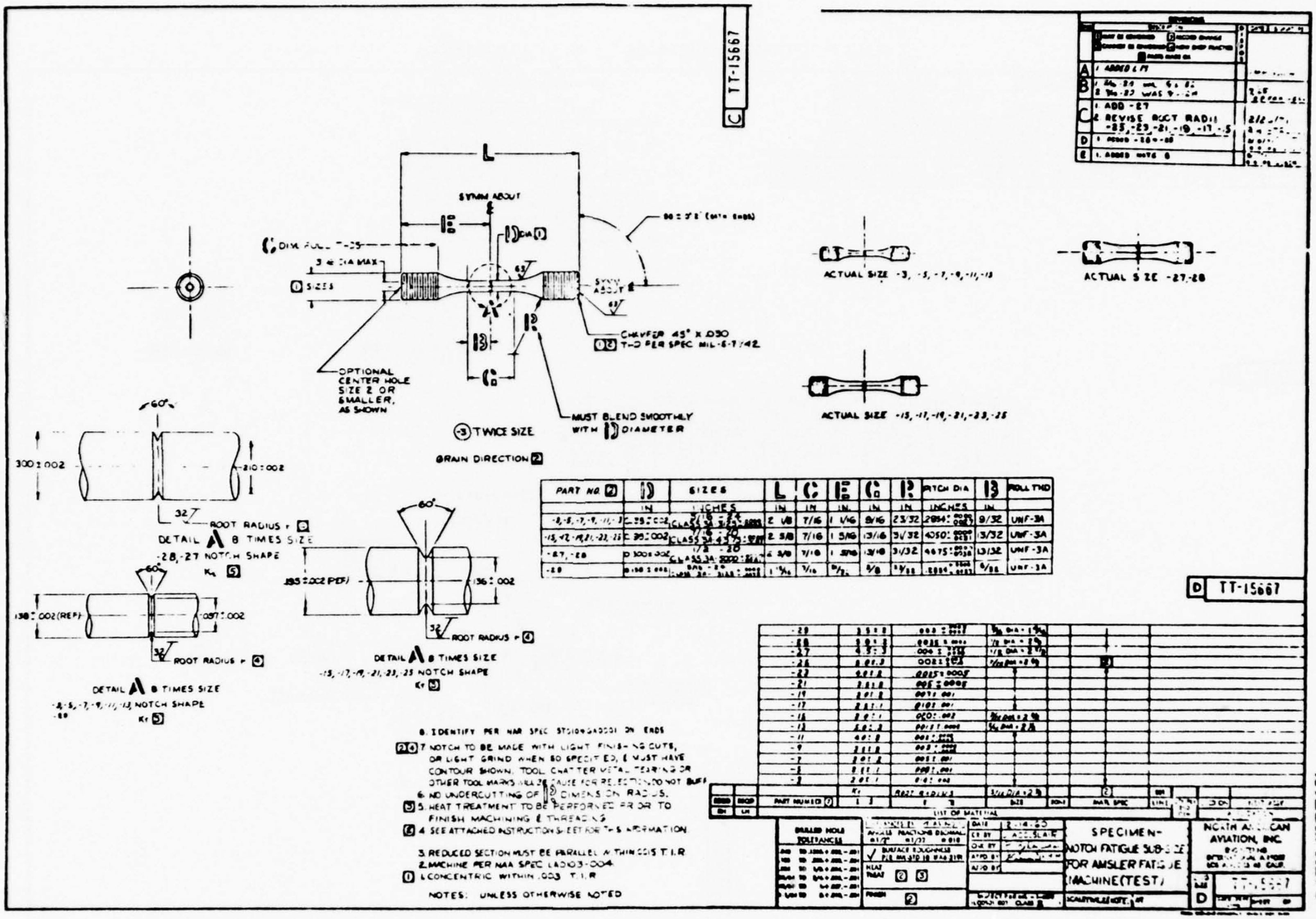


Figure C-8. Test Specimen Drawing - Item 8

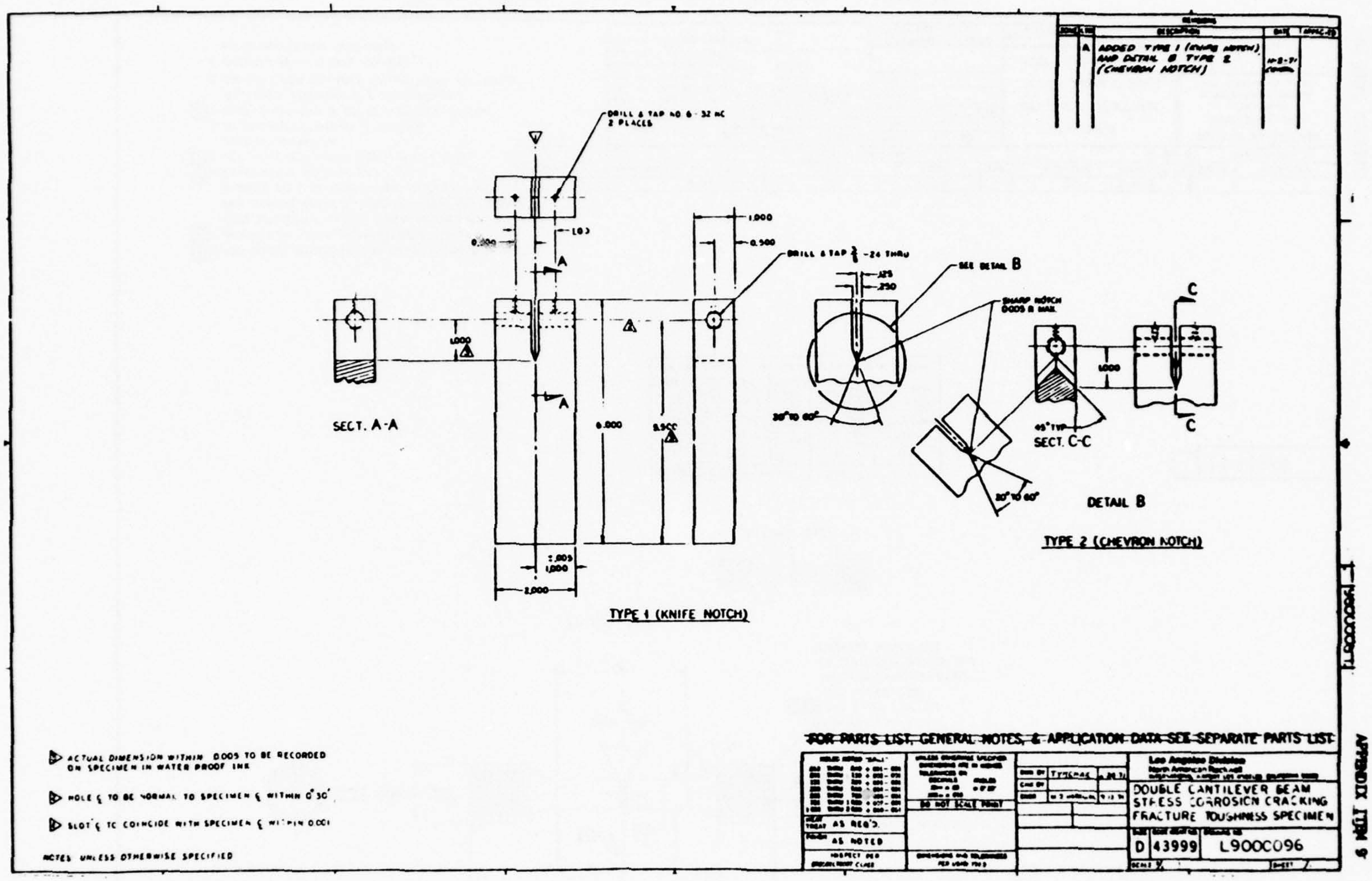


Figure C-9. Test Specimen Drawing - Item 9

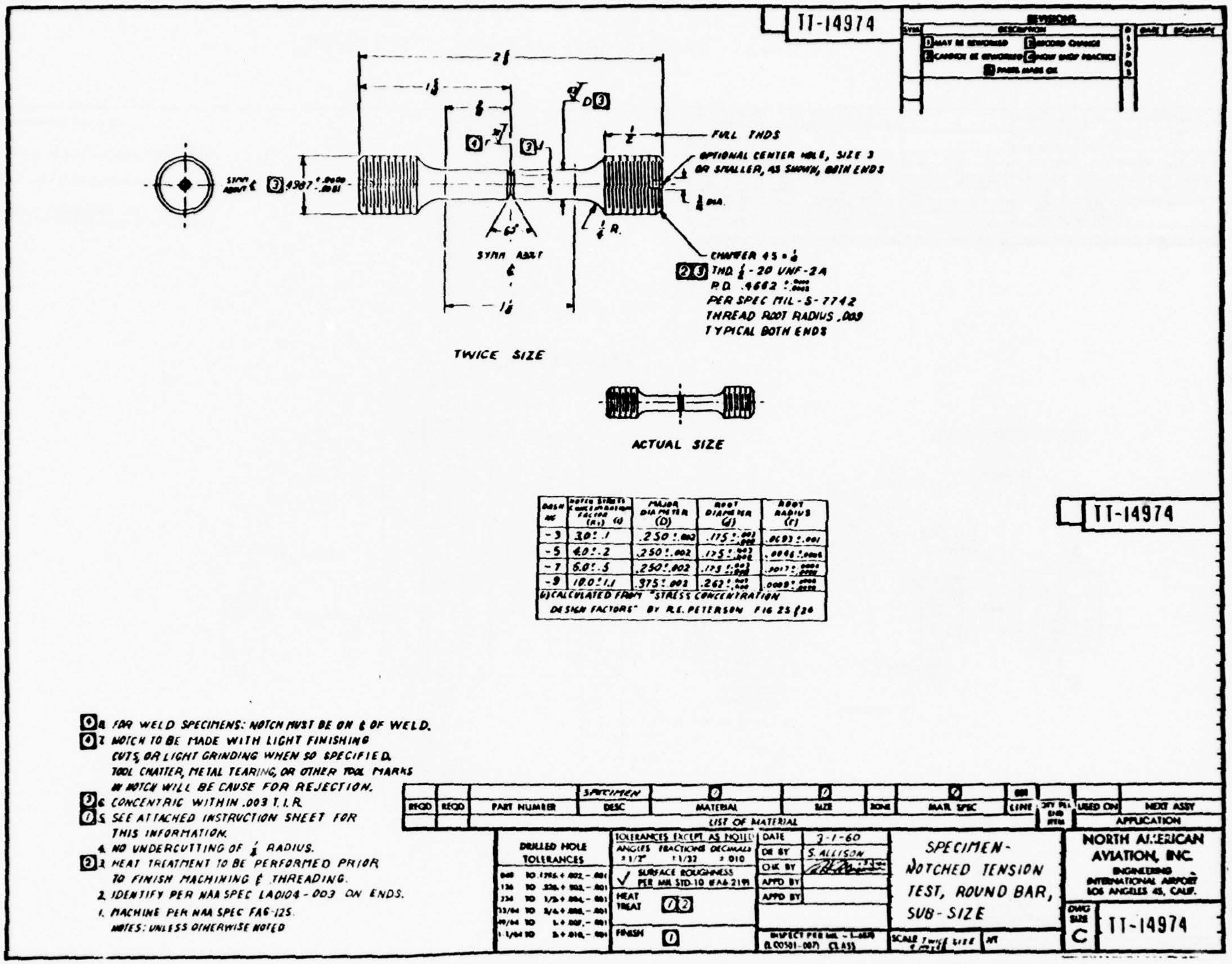


Figure C-10. Test Specimen Drawing - Item 10

APPENDIX D

FATIGUE CRACK GROWTH DATA (da/dN)

SPACE DIVISION
NORTH AMERICAN ROCKWELL CORPORATION

MATERIAL AND PROCESS PROCEDURE

NUMBER: 3320-020

TITLE: CONSTANT AMPLITUDE CYCLIC CRACK GROWTH RATE TEST - COMPACT TENSION SPECIMEN

DATE: December 4, 1973

1. GENERAL:

This procedure describes the method for determining the cyclic crack growth rate of metallic materials. The test is performed by applying a constant amplitude cyclic load to a compact tension (C.T.) test specimen. This test may be performed at other than room temperature and/or lab air environments.

2. REFERENCES:

2.1 L&T Standard Specimen Drawing, L&T Std. No. 0069, "Test Specimen - Compact Tension".

2.2 ASTM Standard E399-72, "Plane Strain Fracture Toughness of Metallic Materials".

2.3 SD Report No. SD73-SH-0070, "Cyclic Crack Growth in Aluminum Alloy 2024-T851".

3. EQUIPMENT:

3.1 Test Machine - A closed loop, servo-controlled electro hydraulic test machine shall be used for these tests. The machine shall operate in load control mode and shall be capable of stable cyclic operation up to 40 Hertz. An amplitude measurement system and two trace oscilloscope shall be available for continuous monitoring of load and COD during testing. Load versus crack opening displacement (COD) shall be autographically recorded. The output signals to the recording device shall be 0 to 10 volts full scale.

3.2 Crack Opening Displacement Gage Transducer: The crack opening displacement (COD) shall be measured with a double-cantilever, resistance strain gaged, clip on displacement gage transducer. The gage shall be similar to the displacement gage described in reference 2.2.

3.3 Load Cell Transducer: The force applied to the test specimen shall be measured with a load cell transducer which is fatigue rated and temperature compensated. The sensing element shall be hermetically sealed within the load cell body and shall consist of resistance strain gages electrically connected to form a balanced wheatstone bridge. Signal output shall be free from the effects of drift, creep, ambient temperature changes, hysteresis, or resonance from static loading up to 50 Hertz.

3.4 Clevises: Load shall be applied to the test specimen with two matched clevises. The load line shall go through the center of each clevis. The loading holes shall be 1.50 inch diameter minimum. The load pins shall be 1.200 inch diameter. The clevis shall be capable of maintaining specimen vertical alignment, either with a close fitting clevis or with spacers between the specimen and clevis inside walls.

4. PROCEDURE:

4.1 Test Specimen: The compact tension test specimen shall conform to the L&T Standard specimen drawing, reference 2.1.

4.1 (Continued)

Note: A test specimen other than the reference 2 specimen size may be tested as long as the specimen dimensions are all a constant ratio of the reference 2 specimen dimensions and the paragraph 3.3 clevises and loading pins are resized with this same ratio.

4.2 Test System Calibration: The test system shall be calibrated prior to the start of test and at six month intervals during testing. Calibration shall also be performed anytime a transducer or test system component is changed or anytime a testing error occurs which could cause the system to exceed transducer limitations. The system shall be calibrated as a complete unit from the point of input to the transducer to final signal output at the recorder. The calibration standards which are used shall be traceable to the National Bureau of Standards.

The load and the COD measuring channels shall be calibrated in 10 equal increments for the ranges being used. Either shunt resistance calibration techniques or master load cell calibration techniques may be used to calibrate the load weighing system. COD system calibration shall be performed with a frame micrometer with 0.0001 inch or less thimble graduations. The maximum allowable error at the test system recorder shall be $\pm$ 0.5% of full scale at each of the 10 increments. The COD gage must be calibrated at the temperature and the environment in which the testing is going to be performed. The load cell must be adequately protected to ensure that ambient conditions exist at the load cell during all testing.

4.3 Test Setup: The test setup shall be as shown schematically in Figure 1.

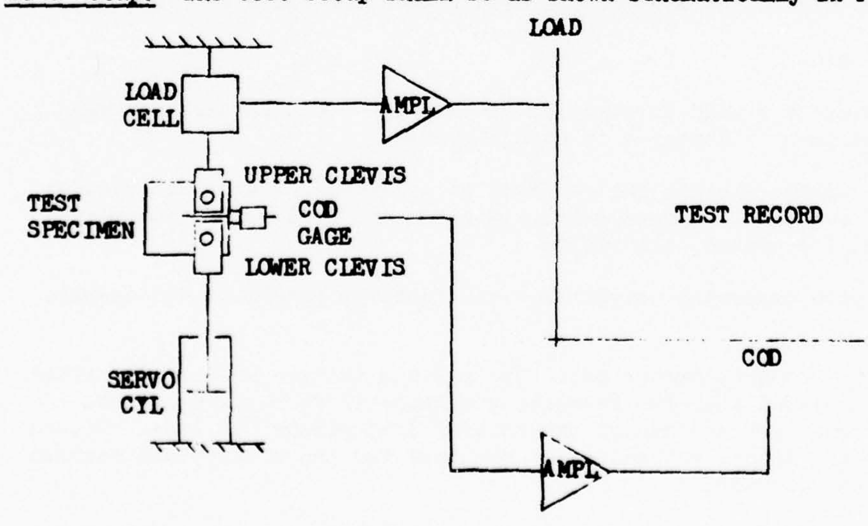


FIGURE 1, TEST SETUP

4.3 (Continued)

Necessary fixturing shall be used so that the clevises are horizontally rigid, so that the load line passes through the center line of each clevis, and so that the loading pins are parallel and vertical within 0.0005 inch as measured outside the clevises.

4.4 Crack Growth Rate Test Conduct: Test specimen size, maximum cyclic load, minimum cyclic load or load ratio (minimum load/maximum load) and cyclic frequency shall be specified by the test request (TR). Load amplitude may be changed during a test if so requested by the TR. If the load is to be changed, the TR must specify the crack length where the load change will occur. The testing agency shall infer this crack length based on the slope of the load versus COD record as explained in section 5 of this M&P procedure.

4.4.1 Select the load and COD ranges so that the load versus COD record is approximately 60° from the horizontal and covers approximately 50% of the load range.

4.4.2 Select load control mode.

4.4.3 Install specimen in upper clevis with COD gage attached.

4.4.4 Adjust load and COD channels for zero volts output with the appropriate zero suppression potentiometers. Adjust load and COD recorder outputs to zero.

4.4.5 Raise hydraulic cylinder rod and lower clevis into position with the valve balance potentiometer. Trim the valve balance potentiometer so that the lower clevis stops in the desired position (float the ram with zero load).

4.4.6 Install lower pin.

Note: If spacers are used to position specimen, install spacers so that the specimen is centered in each clevis.

4.4.7 Load specimen to the minimum fatigue load as specified on the test request (TR) with the set point potentiometer. Monitor the load on the recorder which was used for system calibration.

4.4.8 Select a positive haversine output from the function generator and operate at 0.1 Hertz.

4.4.9 Adjust the Span 2 potentiometer until the maximum fatigue load as specified on the TR is achieved when the function generator is at maximum output. Lower the recorder pen and record the initial load versus COD line. Record the set point and Span 2 potentiometer settings for the minimum and maximum loads. Zero the counter.

4.4.10 Select reference on the oscilloscope input selector Ya channel. Select 0.1 volts per division on the oscilloscope Ya channel.

4.4.11 Set transducer input selector to load.

4.4.12 Adjust amplitude measurement minimum and maximum potentiometers so that two major divisions of oscilloscope beam deflection are achieved when the minimum & maximum loads are achieved.

4.4.13 Put recorder into standby mode.

4.4.14 Increase the function generator frequency until the fatigue cycling is being performed at the TR specified frequency. Visually monitor the load on the oscilloscope while increasing the test frequency and adjust the setpoint and span two potentiometers to maintain two major divisions of oscilloscope deflection at the maximum and minimum force. Record the potentiometer settings for the maximum and minimum loads.

4.4.15 Monitor the COD signal on the oscilloscope Y_b channel while cyclic loading is being applied to the test specimen. When the COD signal has increased by 0.1 volt stop the test machine.

4.4.16 Adjust the set point and span 2 potentiometers to the values determined in 4.4.9.

4.4.17 Turn the recorder servos on. Adjust the recorder X-axis position potentiometer so that the pen is positioned 0.2 inches from the previous load versus COD record.

4.4.18 Operate the test system at 0.1 Hertz.

4.4.19 Lower the recorder pen and record the load versus COD line.

4.4.20 Stop the test machine & turn the recorder off.

4.4.21 Record the number of cycles (from the counter) and testing frequency immediately next to the load versus COD line. Also, when required by the TR, visually measure the crack under 10X magnification minimum and record the crack depth (a=__) immediately adjacent to the load versus COD line.

4.4.22 Adjust the set point and span 2 potentiometers to the values determined in 4.4.14.

4.4.23 Decrease the span potentiometer 2%.

4.4.24 Operate the test system at the TR specified frequency. Monitor the oscilloscope Ya channel (load signal via the amplitude measurement system). Adjust the set point and span 2 potentiometers to obtain two major divisions of oscilloscope beam deflection at the maximum and minimum force.

Note: Extreme care must be exercised to ensure that the specimen is not overloaded during start up and adjustment of the span 2 potentiometer. Overload would introduce retardation and bias test results. <u>If an overload occurs, it must be so noted on the test record.</u>

4.4.25 Repeat steps 4.4.15 through 4.4.24.

4.4.26 Cycle the specimen using procedures 4.4.15 through 4.4.24 until specimen failure occurs. If the load amplitude must be changed during a test because of TR requirements start the test procedure from 4.4.1 through 4.4.24.

<u>Note:</u> During testing, when the slope of the load versus COD line approaches 30 degrees, decrease the COD magnification so that the slope returns to 60° to 75°.

4.4.27 At the completion of testing remove the test record from the recorder and note the following items on the record.

Date
Test Conductors Name
Test Machine Used
Material
Specimen Number & Size
Testing Environment & Temperature
Load Range
COD Magnification

5. <u>CYCLIC CRACK GROWTH RATE DATA REDUCTION METHOD</u>

5.1 <u>Test Record</u> - The following method for obtaining experimental cyclic crack growth rate data depends on an autographic test record with the features shown in Figure 2.

This typified test record shows a series of load versus COD lines or curves. The lines are drawn on the antographic recorder by the testing machine operator at specified intervals of cyclic crack growth, as described in the previous section. The slope of each line is a direct result of specimen stiffness, which is dependent on crack length. By using known elastic relationships that are unique for the specimen configuration, an inferred measurement of crack length is made. Thus, each line represents a discrete crack length.

In addition to the load COD curves, other necessary information is written on the test record by the machine operator. Included are; the COD magnification factor, the load scale range, and for each load COD line, the cumulative total load cycles as indicated by the testing machine cycle counter at the time the load COD line is recorded. A visual observation of crack length as measured at the surface of the specimen may also appear on the test record. However, visual crack length measurements are not required for data reduction.

5.1 (Cont'd)

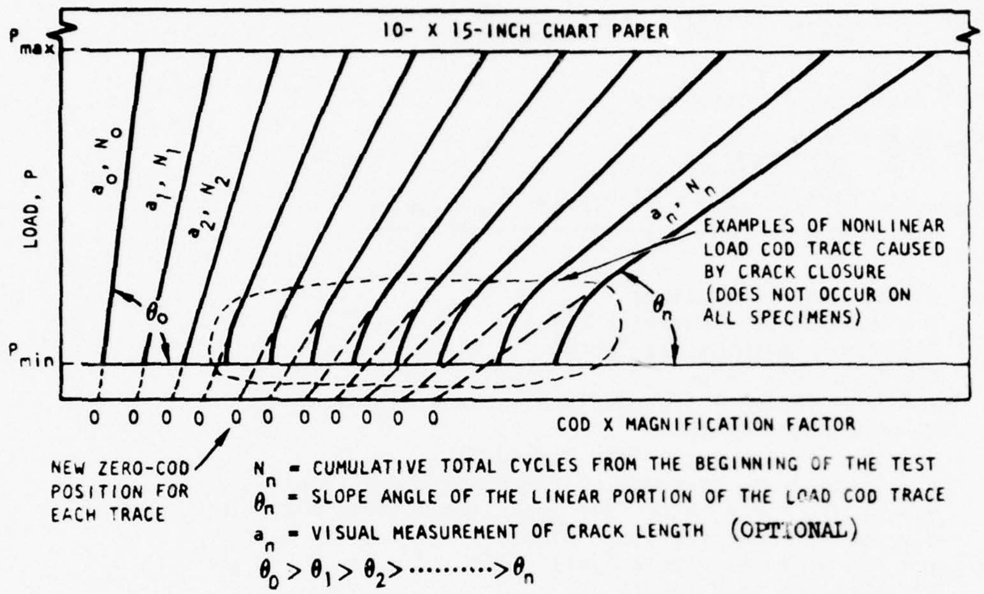


Figure 2 Typical Cyclic Growth Load Record

5.2 **Data Reduction Equations:**

Note: Equations 2 and 4 are valid only for specimens with proportions corresponding to the requirements of paragraph <u>4.1</u> (h/W = 0.6)

1) $CEB = \dfrac{EB}{LF \cdot CM \cdot \tan\theta}$

2) $(a/w) = -0.9496 + 0.4997 \ln(CEB) - 0.04146 \ln^2(CEB) + 0.003728 \ln^3(CEB) - 0.0006902 \ln^4(CEB) + 0.00004396 \ln^5(CEB)$

3) $K = \dfrac{P}{BW^{\frac{1}{2}}} \left[\dfrac{1}{2} \dfrac{d\,(CEB)}{d\,(a/W)}\right]^{\frac{1}{2}} \left[\dfrac{1}{(1-\mu^2)}\right]^{\frac{1}{2}}$

4) $\dfrac{d\,(CEB)}{d\,(a/W)} = EXP\left[C_1 + C_2(\tfrac{a}{W}) + C_3(\tfrac{a}{W})^2 + C_4(\tfrac{a}{W})^3 + C_5(\tfrac{a}{W})^4 + C_6(\tfrac{a}{W})^5\right]$

$X \left[C_2 + 2C_3(\tfrac{a}{W}) + 3C_4(\tfrac{a}{W})^2 + 4C_5(\tfrac{a}{W})^3 + 5C_6(\tfrac{a}{W})^4\right]$

with $C_1 = -0.08045$ $C_3 = -54.92$ $C_5 = -125.1$

$C_2 = 17.91$ $C_4 = 116.1$ $C_6 = 55.97$

5.2 (Cont'd)

5) $$\sigma_{net} = \frac{P}{BW} (1-\frac{a}{W}) \left[1+3 \left[\frac{(1+a/W)}{(1-a/W)}\right]\right]$$

6) $R = P_{min}/P_{max} = K_{min}/K_{max}$

7) $$\frac{da}{dN} \simeq \frac{\Delta a}{\Delta N} = \frac{a_n - a_{(n-1)}}{N_n - N_{(n-1)}}$$

8) $$\Delta K\ avg. = \frac{(1-R_n)\ K_{max_n} + (1-R_{(n-1)})\ K_{max\ (n-1)}}{2}$$

Where:
C = Specimen compliance
E = Modulus of elasticity (psi)
B = Specimen thickness (inch)
μ = Poisson's Ratio
LF = Load Factor - (pounds/inch on vertical axis)
CM = COD Magnification
θ = Load Record Angle (see Figure 2)
a = Crack depth as measured from load line (inch)
W = Specimen dimension from load line to back edge (inch)
K = Stress intensity (psi $\sqrt{\text{inch}}$)
σ_{net} = Net ligament stress (psi)
h = Specimen half-height
P = Load (pounds)
R = Load ratio, or the ratio between the minimum amplitude (P_{min}) and the peak amplitude (P_{max}) of the load cycle.
K_{min} and K_{max} = The stress intensities corresponding to P_{min} and P_{max}.
n = A subscript used to designate the current measurement or observation of pertinent parameters.
$\frac{da}{dN}$ = Cyclic crack growth rate (inches per cycle, or microinches per cycle.)
ΔK = Stress intensity excursion (K_{max}-K_{min}) for a load cycle from P_{min} to P_{max} and corresponding to **a discrete crack length.**
ΔK avg. = Average stress intensity excursion **for** a discrete increment of crack growth, $a = a_n - a_{(n-1)}$.
N = Cumulative total load cycles from the beginning of the test, or from some arbitrary reference point.

5.3 Procedure: Cyclic crack growth rates and related data are derived from the test record in the following manner:

5.3.1 Measure the slope angle, θ_o, of the straight line portion of the first load -COD trace. (See Figure 2)

5.3.2 Calculate normalized compliance, $(CEB)_o$, from equation 1. (LF is the test record load factor in pounds per inch of linear measurement of the vertical axis, CM is the COD magnification recorded in the horizontal direction, and θ is the angle just measured.)

5.3.3 Substitute the just calculated value of $(CEB)_o$ into equation 2 to obtain initial crack length a_o. (W is the width of the CT specimen.)

5.3.4 Calculate $d(CEB)/d(\frac{a}{W})$ by substituting a_o into equation 4.

5.3.5 Calculate K_{max_o} by substituting $d(CEB)/d(\frac{a}{W})$ into equation 3. For the value of load, P_1, use P_{max}. (B is specimen thickness, and μ (mu) is Poisson's ratio.)

5.3.6 Calculate σnet_o from equation 5, using P_{max} and a_o.

5.3.7 Go to the next load - COD trace and measure θ_1.

5.3.8 Calculate $(CEB)_1$ as in para. 5.3.2.

5.3.9 Calculate a, as in para. 5.3.3.

5.3.10 Calculate K_{max_1} as in para. 5.3.4 and 5.3.5.

5.3.11 Calculate σnet_1 as in para 5.3.6.

5.3.12 Calculate R_o and R_1 using equation 6.

Note: Normally $R_n = R_{(n-1)}$. However, if it is desired to take into account the effects of crack closure then R_n does not necessarily equal $R_{(n-1)}$. In that case effective P_{min} is used in equation 6 rather than the actual P_{min} set by the machine operator. Effective P_{min} is the load at which the load - COD line deviates from linearity at the lower end.

5.3.13 Calculate da/dN from equation 7.

5.3.14 Calculate ΔK_{avg} from equation 8.

5.3.15 Go to the next load - COD trace and repeat para. 5.3.7 through 5.3.14. Continue the same process for each load - COD trace on the load record.

Caution: In case the load amplitude, P_{max}, and P_{min} were changed to higher or lower values during the test, do the following to get a valid calculation of ΔK_{avg}:

5.3.15.1 When all calculations (steps 7 through 14) have been made for the last load - COD trace before the change in load amplitude, go back and calculate K_{max} and R for the same load - COD trace but with the new values of P_{min} and P_{max}. Then go to the next load - COD trace and proceed normally. At 5.3.14 when it is time to calculate K_{avg}, substitute this second pair of values of R and K_{max} into equation 8 in place of $R_{(n-1)}$ and K_{max} (n-1).

5.3.15.2 The reason for this variation in procedure is that ΔK_{avg} is an average stress intensity for a discrete increment of growth, and the initial and final stress intensities and load ratios for this increment, that are used to calculate the average value, must be calculated with the same P_{min} and P_{max}.

5.3.15.3 The foregoing procedure is not necessary if during the test conduct, the technician drew an extra load - COD trace whenever the load amplitude was changed. That is, at the end of a period of growth at one load amplitude, a load - COD trace was drawn. Then, before cyclic growth was begun at a new load, a second load - COD line was drawn to represent the starting point for the new load conditions. Obviously, these two lines would represent $\Delta a = 0$ and $\Delta N = 0$ and no growth rate should be reported for the interval.

5.3.16 Plot all values of da/dN and ΔK_{avg} on log - log paper with ΔK_{avg} shown as ΔK on the vertical axis.

5.3.17 Tabulate the following data for each growth increment in the same sequence that the load record followed:

Cyclic Frequency	N
LF	R
CM	a
P_{min}	σ_{net}
P_{max}	K_{max}
θ	da/dN
	ΔK_{avg}

5.4 The technical background for the foregoing data reduction method is found in reference 2.3.

/sh

CYCLIC CRACK GROWTH DATA

DATE- 11-9-76 I.D. NO.- A2WRDR-1 .
MATERIAL- AF1410
TEMP. & ENV.- R.T.-Lab Air
SPECIMEN TYPE- C.T. ORIENTATION-

E (MSI)=28.00 FTY (PSI)= 234000 NU= .30
B=1.002 P MIN (LBS)= 400.0 LF= 1250.00
W= 4.95 P MAX (LBS)= 5000.0 CM= 500 R= .080

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	57.462	96820	1.423	9.09	15.16	0.0000	0.000
30.00	56.495	135930	1.470	9.38	15.44	1.2002	14.075
30.00	55.472	158450	1.520	9.69	15.75	1.5108	14.346
30.00	54.625	197440	1.560	9.95	16.01	1.3881	14.609
30.00	53.945	218580	1.592	10.17	16.23	1.5164	14.829

E (MSI)=28.00 FTY (PSI)= 234000 NU= .30
B=1.002 P MIN (LBS)= 320.0 LF= 1250.00
W= 4.95 P MAX (LBS)= 4000.0 CM= 500 R= .080

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	53.871	218581	1.595	8.16	13.00	0.0000	0.000
30.00	53.057	273470	1.633	8.38	13.21	.6934	12.058
30.00	51.975	331460	1.684	8.67	13.50	.8654	12.288
30.00	50.993	380350	1.729	8.95	13.77	.9233	12.543
30.00	50.307	416080	1.760	9.15	13.96	.8757	12.754
30.00	49.304	464560	1.806	9.46	14.24	.9389	12.971
30.00	48.523	499120	1.841	9.70	14.46	1.0198	13.203
30.00	47.635	546250	1.881	9.99	14.72	.8460	13.424
30.00	46.955	571470	1.911	10.22	14.92	1.2064	13.635
30.00	46.169	607750	1.946	10.49	15.16	.9642	13.835
30.00	45.872	621010	1.959	10.59	15.24	.9941	13.984

E (MSI)=28.00 FTY (PSI)= 234000 NU= .30
B=1.002 P MIN (LBS)= 320.0 LF= 1250.00
W= 4.95 P MAX (LBS)= 4000.0 CM= 200 R= .080

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	67.510	663770	2.041	11.28	15.82	1.9225	14.288

A2WRDR-1

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	66.059	728180	2.129	12.08	16.46	1.3659	14.846
30.00	64.826	781830	2.200	12.79	17.00	1.3221	15.390
30.00	63.435	826290	2.277	13.61	17.61	1.7177	15.922
30.00	61.898	868860	2.357	14.56	18.30	1.8845	16.520
30.00	61.014	897520	2.401	15.13	18.70	1.5478	17.020
30.00	59.801	925160	2.460	15.93	19.26	2.1312	17.461
30.00	58.617	950950	2.516	16.74	19.82	2.1513	17.976
30.00	57.462	971820	2.568	17.56	20.38	2.5090	18.492
30.00	56.335	988960	2.618	18.38	20.94	2.8885	19.009
30.00	55.239	1004520	2.664	19.22	21.51	3.0136	19.530
30.00	54.171	1019320	2.709	20.06	22.09	3.0057	20.056
30.00	52.765	1033360	2.766	21.21	22.87	4.0494	20.681
30.00	51.975	1042830	2.797	21.89	23.33	3.2956	21.254
30.00	50.923	1052940	2.836	22.81	23.95	4.0258	21.757
30.00	49.970	1061590	2.874	23.68	24.56	4.1832	22.321
30.00	49.173	1068930	2.904	24.43	25.08	4.0496	22.832
30.00	47.950	1077370	2.948	25.63	25.90	5.3082	23.447
30.00	46.650	1085400	2.995	26.96	26.82	5.7969	24.248
30.00	45.932	1090340	3.020	27.73	27.34	5.1236	24.913

E (MSI)=28.00 FTY (PSI)= 234000 NU= .30
B=1.002 P MIN (LBS)= 320.0 LF= 1250.00
W= 4.95 P MAX (LBS)= 4000.0 CM= 100 R= .080

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	62.797	1098720	3.080	29.66	28.68	7.1058	25.769
30.00	61.809	1106070	3.120	31.09	29.66	5.5215	26.835
30.00	59.544	1116640	3.207	34.50	32.00	8.2255	28.363
30.00	58.284	1122420	3.253	36.48	33.35	7.8131	30.062
30.00	56.495	1128780	3.313	39.41	35.33	9.5273	31.594
30.00	55.239	1132570	3.353	41.56	36.76	10.6484	33.160
30.00	54.397	1135180	3.380	43.04	37.73	10.0107	34.266
30.00	53.277	1138200	3.413	45.06	39.05	11.1568	35.322
30.00	51.131	1142930	3.475	49.12	41.65	12.9882	37.124
30.00	49.107	1146520	3.529	53.19	44.18	15.2126	39.482
30.00	47.139	1149160	3.580	57.40	46.71	19.0995	41.811
10.00	45.404	1151520	3.622	61.32	49.01	17.9987	44.031
10.00	43.712	1153290	3.662	65.37	51.30	22.5182	46.139
10.00	42.119	1154720	3.698	69.40	53.50	25.3637	48.209
10.00	40.715	1155940	3.729	73.15	55.49	25.4387	50.138
10.00	39.111	1157120	3.764	77.67	57.81	29.2391	52.119
10.00	37.740	1158060	3.793	81.75	59.84	30.6355	54.118
10.00	36.529	1158810	3.818	85.55	61.66	33.2320	55.891
10.00	35.576	1159360	3.837	88.67	63.12	35.1105	57.402

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HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
10.00	34.263	1160060	3.863	93.19	65.17	37.5070	59.017
10.00	37.022	1160500	3.808	83.98	60.92	0.0000	0.000
10.00	33.306	1160500	3.882	96.65	66.70	39.6118	60.713
5.00	32.330	1160850	3.901	100.33	68.28	54.4547	62.088
5.00	31.404	1161190	3.919	103.99	69.80	52.7376	63.517
5.00	30.495	1161510	3.937	107.75	71.33	54.6123	64.920
5.00	29.549	1161820	3.955	111.85	72.95	58.3428	66.365
5.00	28.920	1162030	3.967	114.69	74.04	56.9726	67.612
5.00	28.136	1162250	3.981	118.37	75.42	67.6509	68.752
5.00	27.342	1162430	3.997	122.28	76.85	83.6121	70.047
5.00	26.750	1162607	4.008	125.31	77.94	63.3649	71.203
5.00	26.092	1162754	4.020	128.81	79.16	84.7827	72.266
5.00	25.612	1162841	4.029	131.46	80.07	104.4932	73.247
3.00	24.964	1162958	4.042	135.17	81.32	105.2777	74.238
3.00	24.385	1163069	4.053	138.63	82.45	99.4601	75.334
3.00	23.906	1163165	4.062	141.60	83.41	95.5333	76.296
3.00	23.228	1163262	4.075	145.99	84.79	134.3497	77.371
3.00	22.705	1163345	4.085	149.54	85.88	122.0417	78.506
3.00	22.203	1163415	4.095	153.09	86.94	139.5741	79.497
3.00	22.203	1163415	4.095	153.09	86.94	139.5741	79.497
3.00	21.801	1163482	4.103	156.04	87.81	117.7144	80.386
3.00	21.261	1163539	4.113	160.18	89.00	187.3845	81.335
3.00	20.876	1163591	4.121	163.26	89.87	147.7112	82.282
3.00	20.490	1163645	4.129	166.45	90.76	143.7749	83.089
3.00	20.104	1163689	4.137	169.77	91.66	178.1207	83.913
1.00	19.877	1163706	4.141	171.80	92.20	274.0025	84.578
1.00	19.487	1163746	4.149	175.37	93.15	201.1489	85.261
1.00	19.111	1163787	4.157	178.96	94.08	191.1410	86.122

CYCLIC CRACK GROWTH DATA

DATE- 11-16-76 I.D. NO.- A2WRDR-2
MATERIAL- AF1410 Steel
TEMP. & ENV.- RT. - Lab Air
SPECIMEN TYPE- C.T ORIENTATION-

E (MSI)=28.00	FTY (PSI)= 234000	NU= .30
B=1.001	P MIN (LBS)= 320.0	LF= 1250.00
W= 4.94	P MAX (LBS)= 4000.0	CM= 500 R= .080

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	57.789	138530	1.405	7.21	12.07	0.0000	0.000
30.00	56.896	218680	1.448	7.42	12.27	.5429	11.196
30.00	56.178	281010	1.483	7.59	12.44	.5555	11.357
30.00	55.628	321330	1.509	7.72	12.57	.5535	11.505
30.00	54.931	380380	1.542	7.90	12.75	.5567	11.647
30.00	54.095	436940	1.582	8.11	12.96	.7036	11.823
30.00	52.189	564380	1.670	8.62	13.46	.6970	12.150
30.00	50.240	674530	1.760	9.18	13.99	.8106	12.626
30.00	48.331	766800	1.846	9.78	14.53	.9345	13.121
30.00	46.711	847770	1.918	10.31	15.01	.8945	13.590

E (MSI)=28.00	FTY (PSI)= 234000	NU= .30
B=1.001	P MIN (LBS)= 320.0	LF= 1250.00
W= 4.94	P MAX (LBS)= 4000.0	CM= 200 R= .080

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
~~30.00~~	~~68.396~~	847770	1.982	~~10.81~~	15.44	0.0000	~~0.000~~
30.00	68.595	900010	1.969	10.71	15.35	0.0000	0.000
30.00	67.120	969460	2.062	11.50	16.01	1.3422	14.423
30.00	65.772	1040730	2.142	12.26	16.60	1.1299	14.999
30.00	64.080	1104940	2.238	13.24	17.35	1.4867	15.615
30.00	62.706	1157480	2.311	14.07	17.96	1.3973	16.239
30.00	61.631	1196000	2.366	14.75	18.44	1.4316	16.741
30.00	60.317	1233110	2.431	15.60	19.04	1.7482	17.240
30.00	59.205	1258250	2.484	16.35	19.56	2.1044	17.755
30.00	57.789	1285280	2.549	17.34	20.24	2.4038	18.307
30.00	56.815	1305240	2.592	18.05	20.72	2.1665	18.842
30.00	55.706	1323720	2.640	18.88	21.29	2.5943	19.325
30.00	54.397	1339960	2.695	19.90	21.98	3.3796	19.905
30.00	53.277	1355280	2.741	20.81	22.60	2.9801	20.509
30.00	52.404	1366190	2.776	21.54	23.10	3.1899	21.024

A2WRDR-2

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	51.201	1379150	2.823	22.59	23.82	3.6176	21.583
30.00	50.307	1387490	2.857	23.40	24.37	4.0859	22.165
30.00	49.304	1396240	2.894	24.33	25.01	4.2914	22.714
30.00	48.395	1403700	2.928	25.21	25.62	4.4842	23.288
30.00	47.386	1410870	2.964	26.23	26.31	5.0879	23.887
30.00	46.529	1416120	2.995	27.12	26.93	5.8079	24.489
30.00	45.696	1422110	3.024	28.01	27.54	4.8824	25.056

E (MSI)=28.00 FTY (PSI)= 234000 NU= .30
B=1.001 P MIN (LBS)= 320.0 LF= 1250.00
W= 4.94 P MAX (LBS)= 4000.0 CM= 100 R= .080

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	63.895	1422110	3.028	28.14	27.63	0.0000	0.000
30.00	62.526	1431490	3.086	30.08	28.97	6.2357	26.036
30.00	61.014	1441000	3.147	32.30	30.49	6.3796	27.351
30.00	59.715	1447380	3.196	34.27	31.84	7.7084	28.675
30.00	58.533	1452810	3.239	36.12	33.11	7.8531	29.878
30.00	57.300	1457850	3.281	38.12	34.46	8.4455	31.080
30.00	56.178	1461790	3.319	39.99	35.72	9.4171	32.280
30.00	54.854	1466010	3.361	42.28	37.23	9.9517	33.555
30.00	53.721	1469280	3.395	44.30	38.56	10.5643	34.863
30.00	52.548	1472310	3.430	46.47	39.96	11.3903	36.117
30.00	50.240	1477250	3.494	50.94	42.79	13.0592	38.063
30.00	48.395	1480480	3.543	54.75	45.12	15.0738	40.440
30.00	46.529	1483250	3.590	58.82	47.55	16.9599	42.631
30.00	44.658	1485490	3.635	63.15	50.05	20.1221	44.897
30.00	42.957	1487370	3.674	67.33	52.38	20.9734	47.119
30.00	41.507	1488820	3.707	71.09	54.41	22.4296	49.125
30.00	39.994	1490050	3.740	75.23	56.58	26.8531	51.055
30.00	38.749	1491050	3.766	78.82	58.39	26.5227	52.867
30.00	37.230	1492060	3.798	83.43	60.66	31.3425	54.764
30.00	36.167	1492710	3.820	86.83	62.27	33.4623	56.548
30.00	34.890	1493360	3.846	91.11	64.25	39.5273	58.201
30.00	33.903	1493880	3.865	94.59	65.81	37.6822	59.827
30.00	32.661	1494460	3.889	99.19	67.80	41.9872	61.462
30.00	31.845	1494780	3.905	102.36	69.14	49.4949	62.995
30.00	30.944	1495150	3.923	106.01	70.64	46.9741	64.301
30.00	30.058	1495480	3.940	109.75	72.14	51.3943	65.682
30.00	29.136	1495780	3.957	113.85	73.74	58.5802	67.105
30.00	28.523	1495990	3.969	116.68	74.81	55.4174	68.333
30.00	27.734	1496220	3.984	120.48	76.22	65.0478	69.477
30.00	26.819	1496410	4.001	125.10	77.89	91.0860	70.893

A2WKDR-2

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	26.136	1496590	4.014	128.73	79.16	71.8626	72.245
30.00	25.485	1496760	4.026	132.34	80.40	72.6599	73.400
30.00	24.842	1496890	4.039	136.06	81.64	93.8658	74.540
30.00	24.327	1497000	4.048	139.16	82.66	89.3551	75.578

CYCLIC CRACK GROWTH DATA

DATE- 11-15-76 I.D. NO.- A2RWDR-1
MATERIAL- AF 1410 STEEL
TEMP. & ENV.- RT. Lab Air
SPECIMEN TYPE- CT ORIENTATION-

E (MSI)=28.00 FTY (PSI)= 234000 NU= .30
B= .998 P MIN (LBS)= 280.0 LF= 1250.00
W= 4.94 P MAX (LBS)= 3500.0 CM= 500 R= .080

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	56.178	303980	1.479	6.64	10.90	0.0000	0.000
30.00	55.085	422570	1.531	6.88	11.13	.4401	10.137
30.00	53.871	528870	1.588	7.15	11.40	.5390	10.367
30.00	53.425	601050	1.609	7.25	11.50	.2891	10.538
30.00	53.057	636480	1.626	7.34	11.59	.4838	10.623
30.00	52.548	679450	1.650	7.46	11.71	.5499	10.716
30.00	51.621	758070	1.693	7.69	11.92	.5441	10.870
30.00	50.648	836710	1.737	7.93	12.16	.5662	11.078
30.00	50.037	889110	1.765	8.09	12.31	.5309	11.254
30.00	49.239	971500	1.801	8.30	12.51	.4388	11.414
30.00	48.267	1029600	1.845	8.57	12.75	.7530	11.617
30.00	47.386	1099100	1.884	8.83	12.97	.5678	11.833
30.00	46.469	1162520	1.925	9.10	13.21	.6446	12.046
30.00	45.462	1221380	1.970	9.41	13.48	.7591	12.279
30.00	44.658	1274360	2.006	9.67	13.70	.6710	12.500

E (MSI)=28.00 FTY (PSI)= 234000 NU= .30
B= .998 P MIN (LBS)= 280.0 LF= 1250.00
W= 4.94 P MAX (LBS)= 3500.0 CM= 200 R= .080

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	67.706	1274360	2.022	9.79	13.80	0.0000	0.000
30.00	66.636	1358220	2.088	10.30	14.21	.7851	12.883
30.00	64.920	1471830	2.187	11.15	14.87	.8796	13.378
30.00	63.619	1536040	2.259	11.83	15.38	1.1175	13.914
30.00	62.166	1607960	2.336	12.61	15.94	1.0617	14.407
30.00	60.926	1654590	2.398	13.30	16.43	1.3375	14.893
30.00	59.374	1707480	2.473	14.20	17.06	1.4133	15.409
30.00	58.201	1742690	2.527	14.92	17.55	1.5429	15.924
30.00	56.896	1773330	2.585	15.74	18.12	1.9062	16.408
30.00	55.706	1801050	2.637	16.52	18.65	1.8583	16.911

30.00	54.549	1822880	2.686	17.30	19.18	2.2287	17.402

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	53.277	1842060	2.738	18.20	19.80	2.7103	17.930
30.00	52.046	1862050	2.786	19.11	20.42	2.4475	18.497
30.00	50.786	1877730	2.835	20.08	21.08	3.1104	19.088
30.00	49.569	1892470	2.881	21.07	21.75	3.1160	19.702
30.00	48.652	1903200	2.915	21.83	22.28	3.1611	20.254
30.00	47.510	1913600	2.957	22.83	22.96	3.9878	20.811
30.00	46.650	1922250	2.987	23.61	23.50	3.5507	21.373
30.00	45.696	1931040	3.021	24.50	24.12	3.8186	21.903
30.00	44.715	1937760	3.055	25.46	24.78	5.0583	22.490

E (MSI)=28.00 FTY (PSI)= 234000 NU= .30
B= .998 P MIN (LBS)= 280.0 LF= 1250.00
W= 4.94 P MAX (LBS)= 3500.0 CN= 100 R= .080

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	63.435	1937760	3.045	25.18	24.58	0.0000	0.000
30.00	61.542	1951060	3.123	27.56	26.22	5.8970	23.370
30.00	60.144	1959800	3.178	29.40	27.48	6.1857	24.705
30.00	58.617	1968760	3.233	31.48	28.90	6.2217	25.939
30.00	57.381	1975370	3.276	33.23	30.09	6.4803	27.136
30.00	57.381	1975370	3.276	33.23	30.09	6.4803	27.136
30.00	55.941	1981730	3.324	35.33	31.50	7.4790	28.331
30.00	54.778	1986830	3.360	37.10	32.67	7.2123	29.519
30.00	53.499	1991290	3.399	39.11	33.98	8.7183	30.662
30.00	52.117	1995430	3.440	41.35	35.44	9.7344	31.934
30.00	49.436	2002450	3.513	45.99	38.34	10.5074	33.939
30.00	47.016	2007520	3.576	50.50	41.07	12.2766	36.532
30.00	45.057	2010800	3.623	54.41	43.35	14.5597	38.835
30.00	43.440	2013520	3.661	57.84	45.28	14.4394	40.740
30.00	41.710	2015860	3.700	61.73	47.40	16.7405	42.633
30.00	40.089	2017770	3.736	65.58	49.43	18.6056	44.539
30.00	38.437	2019520	3.771	69.76	51.54	20.1160	46.446
30.00	36.939	2020830	3.802	73.79	53.51	23.7775	48.326
30.00	35.538	2021930	3.831	77.79	55.39	25.9295	50.095
30.00	34.335	2022850	3.855	81.41	57.04	26.1590	51.720
30.00	33.134	2023700	3.879	85.23	58.72	27.9014	53.252
30.00	32.102	2024310	3.899	88.68	60.20	33.0224	54.704
30.00	30.793	2024980	3.924	93.31	62.11	37.7680	56.261
30.00	29.745	2025500	3.944	97.24	63.68	38.6180	57.861
30.00	28.787	2025960	3.962	101.03	65.14	39.7103	59.254
30.00	27.984	2026330	3.978	104.36	66.39	41.2191	60.503
30.00	27.150	2026670	3.994	107.99	67.71	46.5391	61.688
30.00	26.315	2026980	4.009	111.81	69.07	51.0436	62.921
30.00	25.785	2027200	4.019	114.34	69.95	45.7479	63.948
30.00	25.129	2027430	4.032	117.60	71.05	54.2379	64.859

CYCLIC CRACK GROWTH DATA

DATE- 12-15-76 I.D. NO.- A2WRDR-7
MATERIAL- AF1410
TEMP. & ENV.- R.T. Lab Air.
SPECIMEN TYPE- C.T. ORIENTATION-

E (MSI)=28.00 FTY (PSI)= 234000 NU= .30
B= .998 P MIN (LBS)=1380.0 LF= 1250.00
W= 4.94 P MAX (LBS)= 4600.0 CM= 500 R= .300

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	57.057	234000	1.436	8.49	13.44	0.0000	0.000
30.00	56.178	308610	1.479	8.73	13.67	.5686	9.439
30.00	55.008	385370	1.534	9.06	13.98	.7274	9.678
30.00	54.171	444290	1.574	9.31	14.21	.6708	9.869
30.00	52.548	547140	1.650	9.81	14.68	.7363	10.112
30.00	50.854	636530	1.728	10.36	15.18	.8714	10.451
30.00	49.370	708580	1.795	10.87	15.64	.9357	10.788
30.00	47.823	781000	1.865	11.44	16.13	.9608	11.119
30.00	46.349	840060	1.930	12.01	16.61	1.1132	11.457
30.00	44.829	890670	1.998	12.63	17.11	1.3307	11.803

E (MSI)=28.00 FTY (PSI)= 234000 NU= .30
B= .998 P MIN (LBS)=1380.0 LF= 1250.00
W= 4.94 P MAX (LBS)= 4600.0 CM= 200 R= .300

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	66.155	964350	2.116	13.85	18.05	1.6037	12.308
30.00	64.639	1017670	2.203	14.85	18.78	1.6326	12.892
30.00	63.343	1058800	2.274	15.74	19.41	1.7195	13.369
30.00	62.435	1088160	2.321	16.38	19.86	1.6248	13.745
30.00	61.365	1116410	2.376	17.16	20.39	1.9263	14.036
30.00	60.144	1141070	2.436	18.08	21.00	2.4290	14.486
30.00	59.036	1164510	2.488	18.94	21.57	2.2392	14.901
30.00	58.118	1182570	2.530	19.68	22.05	2.3389	15.269
30.00	57.057	1198780	2.578	20.55	22.63	2.9308	15.639
30.00	56.020	1213940	2.623	21.44	23.20	2.9794	16.041
30.00	55.085	1228280	2.663	22.26	23.74	2.7701	16.430
30.00	53.204	1248460	2.740	24.00	24.87	3.8292	17.012
30.00	50.580	1273270	2.843	26.62	26.57	4.1344	18.003
30.00	46.832	1298690	2.980	30.81	29.32	5.4174	19.562
30.00	44.489	1312700	3.062	33.77	31.26	5.8358	21.204

E (MSI)=28.00 FTY (PSI)= 234000 NU= .30
B= .998 P MIN (LBS)=1380.0 LF= 1250.00
W= 4.94 P MAX (LBS)= 4600.0 CM= 100 R= .300

A2 WRDR-7

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	61.365	1323260	3.130	36.53	33.08	6.4261	22.519
30.00	60.317	1329330	3.170	38.34	34.26	6.6734	23.570
30.00	57.953	1339100	3.256	42.60	37.03	8.7504	24.954
30.00	56.020	1346400	3.320	46.29	39.40	8.8499	26.752
30.00	55.085	1349520	3.350	48.15	40.57	9.5334	27.991
30.00	54.095	1352360	3.381	50.16	41.84	10.7456	28.845
30.00	53.277	1354990	3.405	51.87	42.90	9.3173	29.660
30.00	51.333	1358450	3.447	54.99	44.81	12.0806	30.700
30.00	49.239	1365560	3.518	60.92	48.35	9.9700	32.608
30.00	47.698	1368090	3.558	64.67	50.52	15.7510	34.607
30.00	46.229	1370190	3.594	68.41	52.64	17.4285	36.107
30.00	44.602	1371930	3.633	72.78	55.03	22.4745	37.685
30.00	43.386	1373340	3.662	76.19	56.86	20.0943	39.163
30.00	39.572	1376730	3.746	87.90	62.80	24.9493	41.880
30.00	37.399	1378290	3.792	95.35	66.33	29.3116	45.196
30.00	35.383	1379450	3.833	102.86	69.72	35.4505	47.619
30.00	33.585	1380420	3.869	110.12	72.84	36.9009	49.894
30.00	32.102	1381160	3.898	116.57	75.48	39.1984	51.911
10.00	28.974	1382311	3.958	131.81	81.31	52.1898	54.878
10.00	27.318	1382810	3.990	140.96	84.57	63.0113	58.059
10.00	26.225	1383170	4.010	147.54	86.79	57.5576	59.975
10.00	25.212	1383440	4.029	154.04	88.91	71.2523	61.496
10.00	24.269	1383660	4.047	160.50	90.95	81.7481	62.950
10.00	23.372	1383860	4.065	167.07	92.94	86.1006	64.360

CYCLIC CRACK GROWTH DATA

DATE- 1-17-77 I.D. NO.- A2 WRDR-5
MATERIAL- AF1410 STEEL
TEMP. & ENV.- R.T. LAB AIR
SPECIMEN TYPE- C.T. ORIENTATION-

PLANE STRESS

E (MSI)=28.00 B= .997 W= 4.94 FTY (PSI)= 234000 P MIN (LBS)= 280.0 P MAX (LBS)= 3500.0 NU= .30 LF= 1250.00 CM= 500 R= .080

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
1.00	56.495	14110	1.463	6.58	10.34	0.0000	0.000
1.00	55.823	41218	1.495	6.72	10.47	1.1907	9.575
1.00	55.317	68500	1.519	6.83	10.58	.8851	9.684
1.00	54.778	96000	1.545	6.95	10.69	.9302	9.783
30.00	54.778	0	1.545	6.95	10.69	0.0000	0.000
30.00	53.573	108900	1.601	7.22	10.95	.5205	9.952
30.00	52.404	221170	1.656	7.50	11.20	.4843	10.189
30.00	51.410	319920	1.701	7.74	11.43	.4638	10.410

E (MSI)=28.00 B= .997 W= 4.94 FTY (PSI)= 234000 P MIN (LBS)= 320.0 P MAX (LBS)= 4000.0 NU= .30 LF= 1250.00 CM= 500 R= .080

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	49.635	472150	1.782	9.37	13.53	0.0000	0.000
30.00	48.717	520410	1.824	9.65	13.78	.8590	12.563
30.00	46.832	606750	1.908	10.27	14.31	.9778	12.920
30.00	45.230	678000	1.979	10.83	14.77	.9985	13.374

E (MSI)=28.00 B= .997 W= 4.94 FTY (PSI)= 234000 P MIN (LBS)= 350.0 P MAX (LBS)= 4375.0 NU= .30 LF= 1250.00 CM= 500 R= .080

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
1.00	45.000	11020	1.990	11.94	16.23	0.0000	0.000
1.00	44.153	29256	2.027	12.29	16.50	2.0515	15.054
1.00	43.010	55925	2.077	12.78	16.88	1.8878	15.355
1.00	41.556	83699	2.141	13.44	17.37	2.2970	15.757

E (MSI)=28.00 B= .997 W= 4.94 FTY (PSI)= 234000 P MIN (LBS)= 350.0 P MAX (LBS)= 4375.0 NU= .30 LF= 1250.00 CM= 200 R= .080

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	65.392	0	2.160	13.64	17.52	0.0000	0.000

A2WRDR-5

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	64.452	31640	2.213	14.24	17.96	1.6770	16.320
30.00	62.978	67360	2.293	15.21	18.64	2.2317	16.833
30.00	61.587	99980	2.364	16.16	19.29	2.1974	17.446
30.00	60.490	124260	2.419	16.93	19.81	2.2374	17.986
30.00	59.205	148950	2.480	17.88	20.44	2.4859	18.514
30.00	58.118	167330	2.530	18.70	20.98	2.7296	19.052
30.00	57.138	186400	2.574	19.47	21.48	2.3052	19.532
1.00	57.138	0	2.574	19.47	21.48	0.0000	0.000
1.00	55.784	12941	2.633	20.58	22.20	4.5515	20.093
1.00	54.816	23593	2.674	21.39	22.73	3.8396	20.667
1.00	53.204	34956	2.740	22.81	23.65	5.8137	21.336
30.00	53.204	0	2.740	22.81	23.65	0.0000	0.000
30.00	52.010	10200	2.787	23.92	24.37	4.6484	22.091
30.00	50.958	17820	2.828	24.93	25.03	5.3534	22.724
30.00	50.104	24440	2.861	25.78	25.58	4.9069	23.283
30.00	49.140	30450	2.897	26.77	26.23	5.9949	23.835
30.00	48.203	36470	2.931	27.77	26.89	5.7161	24.435
30.00	47.386	41010	2.961	28.67	27.48	6.5070	25.007
30.00	46.529	45680	2.991	29.64	28.12	6.5423	25.573
1.00	46.529	0	2.991	29.64	28.12	0.0000	0.000
1.00	45.637	3833	3.023	30.69	28.81	8.1797	26.184
1.00	44.857	6930	3.050	31.64	29.43	8.7385	26.789
1.00	44.153	9948	3.074	32.52	30.01	8.0048	27.344
1.00	43.359	12420	3.101	33.55	30.69	10.9053	27.922

E (MSI)=28.00   FTY (PSI)= 234000   NU= .30
B= .997   P MIN (LBS)= 350.0   LF= 1250.00
W= 4.94   P MAX (LBS)= 4375.0   CM= 100   R= .080

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	62.076	0	3.102	33.59	30.71	0.0000	0.000
30.00	60.317	7430	3.171	36.45	32.59	9.2952	29.117
30.00	59.205	12670	3.212	38.32	33.81	7.8647	30.542
30.00	58.118	16650	3.251	40.21	35.03	9.7056	31.668
30.00	57.138	19450	3.284	41.96	36.16	11.9749	32.749
30.00	56.257	22620	3.313	43.57	37.19	9.2008	33.741
30.00	55.046	25300	3.352	45.84	38.64	14.4366	34.880
1.00	55.046	0	3.352	45.84	38.64	0.0000	0.000
1.00	53.945	2059	3.386	47.98	39.98	16.4494	36.161
1.00	53.167	3685	3.409	49.53	40.94	14.2895	37.221
1.00	52.117	5436	3.440	51.68	42.26	17.4186	38.270
30.00	52.117	0	3.440	51.68	42.26	0.0000	0.000
30.00	51.201	1730	3.465	53.60	43.43	14.9426	39.415
30.00	50.172	3110	3.494	55.83	44.76	20.4730	40.566

A2 WRDR-5

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	49.370	4490	3.515	57.61	45.81	15.5627	41.664
30.00	48.427	5870	3.540	59.77	47.07	17.8833	42.726
30.00	47.635	6830	3.560	61.62	48.14	21.1188	43.795
30.00	46.741	7960	3.582	63.78	49.36	19.8368	44.848
1.00	46.741	0	3.582	63.78	49.36	0.0000	0.000
1.00	45.696	884	3.608	66.37	50.30	28.9566	46.075
1.00	44.886	1610	3.628	68.44	51.94	26.7661	47.263
1.00	44.153	2214	3.645	70.37	52.98	28.6242	48.264
30.00	44.153	0	3.645	70.37	52.98	0.0000	0.000
30.00	43.117	930	3.669	73.17	54.47	25.7877	49.427
30.00	42.300	1510	3.687	75.45	55.66	31.9986	50.659
30.00	41.659	2060	3.702	77.28	56.60	26.0994	51.639
30.00	41.034	2460	3.715	79.11	57.53	34.5741	52.500
30.00	40.256	2950	3.733	81.45	58.70	34.6852	53.463
30.00	39.665	3320	3.745	83.27	59.59	34.4743	54.411
1.00	39.665	0	3.745	83.27	59.59	0.0000	0.000
1.00	39.157	319	3.756	84.87	60.37	34.0496	55.180
1.00	38.415	633	3.772	87.25	61.51	50.0096	55.062
1.00	37.869	910	3.733	89.06	62.36	41.2896	56.979
1.00	37.251	1163	3.796	91.15	63.33	50.7155	57.816
1.00	36.774	1397	3.806	92.79	64.08	41.9835	58.610
1.00	36.008	1688	3.822	95.51	65.31	53.7423	59.520
1.00	35.615	1859	3.830	96.93	65.94	46.5564	60.375

CYCLIC CRACK GROWTH DATA

DATE- 2-14-77 I.D. NO.- A2WRDR-4
MATERIAL- AF1410 STEEL
TEMP. & ENV.- R.T. 3.5% SALT WATER
SPECIMEN TYPE- C.T. ORIENTATION-

PLANE STRESS

E (MSI)=28.00 FTY (PSI)= 234000 NU= .30
B=1.000 P MIN (LBS)= 560.0 LF= 1000.00
W= 4.94 P MAX (LBS)= 7000.0 CM= 500 R= .080

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
20.00	62.978	27970	1.418	12.74	20.27	0.0000	0.000
20.00	62.390	37150	1.450	13.01	20.53	3.4774	18.767
20.00	61.720	46750	1.486	13.33	20.82	3.7452	19.019
20.00	61.101	58170	1.519	13.62	21.10	2.5565	19.282
20.00	60.490	66870	1.551	13.92	21.38	3.6748	19.538
1.00	60.490	0	1.551	13.92	21.38	0.0000	0.000
1.00	60.317	2300	1.560	14.00	21.46	3.9121	19.704
1.00	59.715	7035	1.591	14.30	21.74	6.5511	19.870
1.00	59.205	12386	1.617	14.56	21.98	4.8655	20.110
1.00	58.617	17440	1.646	14.86	22.26	5.8831	20.350
1.00	58.284	22639	1.663	15.04	22.42	3.2106	20.554
1.00	57.625	27282	1.696	15.38	22.74	7.0539	20.775
1.00	57.452	0	1.704	15.47	22.82	0.0000	0.000
20.00	57.057	8290	1.724	15.69	23.02	2.4038	21.087
20.00	56.495	14600	1.751	16.00	23.30	4.3306	21.306
20.00	55.863	22820	1.782	16.35	23.61	3.7203	21.579
20.00	55.239	30430	1.812	16.71	23.93	3.9220	21.[illegible]
20.00	54.625	35530	1.841	17.07	24.24	4.7758	22.155
20.00	54.625	0	1.841	17.07	24.24	0.0000	0.000
1.00	54.020	3871	1.869	17.43	24.54	7.3513	22.430
1.00	53.573	7820	1.890	17.70	24.77	5.2951	22.[illegible]
1.00	53.204	12509	1.907	17.92	24.96	3.4376	22.879

A2WRDR-4

CYCLIC CRACK GROWTH DATA

DATE-
MATERIAL-
TEMP. & ENV.-
SPECIMEN TYPE-

I.D. NO.-

ORIENTATION-

E (MSI)=28.00 B=1.000 W= 4.94
FTY (PSI)= 234000 P MIN (LBS)= 560.0 P MAX (LBS)= 7000.0
NU= .30 LF= 1000.00 CM= 500 R= .080

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
25.00	52.924	0	1.917	18.06	25.08	0.0000	0.000
25.00	52.620	6140	1.934	18.29	25.26	2.7300	23.157
25.00	52.189	11840	1.954	18.55	25.49	3.4744	23.347
25.00	52.153	18900	1.956	18.59	25.51	.2316	23.459
25.00	51.550	27200	1.983	18.98	25.82	3.3077	23.612
25.00	50.854	35380	2.015	19.44	26.19	3.8489	23.926
1.00	50.854	0	2.015	19.44	26.19	0.0000	0.000
1.00	50.307	3360	2.039	19.81	26.48	7.3146	24.220
1.00	49.769	6846	2.063	20.18	26.77	6.9002	24.495
1.00	49.503	7800	2.075	20.37	26.91	12.4072	24.604
1.00	49.042	11423	2.095	20.70	27.16	5.6351	24.875
25.00	49.042	0	2.095	20.70	27.16	0.0000	0.000
25.00	48.588	6680	2.115	21.03	27.41	3.0009	25.103
25.00	47.448	11160	2.165	21.88	28.04	11.1433	25.508
25.00	47.077	14530	2.182	22.17	28.25	4.7898	25.804
25.00	46.650	18130	2.200	22.50	28.49	5.1470	26.101

E (MSI)=28.00 B=1.000 W= 4.94
FTY (PSI)= 234000 P MIN (LBS)= 560.0 P MAX (LBS)= 7000.0
NU= .30 LF= 1000.00 CM= 200 R= .080

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
25.00	69.093	18130	2.214	22.77	28.68	0.0000	0.000
25.00	68.100	26740	2.277	23.98	29.53	7.2940	26.779
25.00	67.608	32410	2.307	24.59	29.96	5.2957	27.366
25.00	66.926	38340	2.348	25.45	30.55	6.8465	27.831
25.00	66.347	43240	2.381	26.19	31.05	6.8439	28.333
25.00	65.582	48550	2.424	27.19	31.72	8.0993	28.871
1.00	65.582	0	2.424	27.19	31.72	0.0000	0.000
1.00	65.014	4255	2.455	27.94	32.22	7.2967	29.409
1.00	64.219	7130	2.498	29.01	32.93	14.7201	29.965
1.00	63.527	10193	2.534	29.97	33.55	11.6935	30.560

A2WRDK 4

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
25.00	63.527	0	2.534	29.97	33.55	0.0000	0.000
25.00	62.797	4430	2.570	31.00	34.22	8.2908	31.177
25.00	62.121	8190	2.603	31.97	34.85	8.8111	31.775
25.00	61.720	11740	2.623	32.55	35.23	5.4375	32.240
25.00	61.101	15460	2.652	33.46	35.83	7.8522	32.688
25.00	60.577	18710	2.676	34.25	36.34	7.4707	33.196
1.00	60.577	0	2.676	34.25	36.34	0.0000	0.000
1.00	59.715	2319	2.715	35.57	37.20	16.8159	33.826
1.00	59.205	4118	2.738	36.37	37.71	12.5407	34.458
1.00	58.617	5853	2.763	37.30	38.32	14.7373	34.976
1.00	58.036	7490	2.788	38.24	38.93	15.1473	35.536
25.00	58.036	0	2.788	38.24	38.93	0.0000	0.000
25.00	57.340	2380	2.817	39.39	39.68	10.1116	36.160
25.00	56.815	5200	2.839	40.27	40.25	9.2987	36.768
25.00	56.099	7050	2.868	41.49	41.05	15.6347	37.400
25.00	55.706	8680	2.883	42.18	41.50	9.5795	37.973
25.00	55.162	10600	2.905	43.14	42.13	11.1139	38.465
1.00	55.162	0	2.905	43.14	42.13	0.0000	0.000
1.00	54.473	1276	2.931	44.38	42.94	20.8299	39.131
1.00	53.796	2288	2.957	45.62	43.76	25.3585	39.851
1.00	53.351	3218	2.974	46.46	44.30	17.8746	40.509
1.00	52.838	4103	2.992	47.43	44.95	21.3831	41.056
25.00	52.838	0	2.992	47.43	44.95	0.0000	0.000
25.00	52.260	1360	3.013	48.55	45.68	15.4650	41.689
25.00	51.762	2510	3.031	49.53	46.33	15.5636	42.325
25.00	51.096	3820	3.055	50.87	47.21	18.0045	43.027
25.00	50.560	4920	3.073	51.93	47.91	16.4237	43.753
25.00	50.003	5950	3.093	53.14	48.70	19.3302	44.438
1.00	50.003	0	3.093	53.14	48.70	0.0000	0.000
1.00	49.503	770	3.110	54.21	49.40	22.1946	45.125
1.00	48.847	1442	3.132	55.63	50.34	32.9174	45.879
1.00	48.299	2082	3.150	56.85	51.13	28.4845	45.675
1.00	47.886	2678	3.164	57.78	51.75	22.8197	47.324

E (MSI)=28.00 FTY (PSI)= 234000 NU= .30
B=1.000 P MIN (LBS)= 560.0 LF= 1000.00
W= 4.94 P MAX (LBS)= 7000.0 CM= 100 R= .080

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
25.00	65.487	0	3.172	58.36	52.12	0.0000	0.000
25.00	64.733	1490	3.204	60.67	53.63	21.3928	48.644
25.00	64.080	2830	3.231	62.70	54.95	19.8540	49.943
25.00	63.298	4030	3.262	65.17	56.54	25.6723	51.285
25.00	62.616	5100	3.287	67.36	57.95	24.2157	52.669

A2WRDR-4

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
25.00	61.809	6110	3.317	69.99	59.64	29.3397	54.092
1.00	61.809	0	3.317	69.99	59.64	0.0000	0.000
1.00	61.014	581	3.345	72.64	61.32	48.4592	55.639
1.00	60.230	1142	3.372	75.29	62.98	47.7467	57.178
1.00	59.544	1681	3.395	77.65	64.46	42.1903	58.623
1.00	58.868	2164	3.417	80.02	65.92	45.1351	59.974
25.00	58.868	0	3.417	80.02	65.92	0.0000	0.000
25.00	58.201	490	3.437	82.39	67.37	42.6894	61.316
25.00	57.351	910	3.452	85.36	69.17	50.4926	62.813
25.00	56.896	1290	3.477	87.14	70.25	37.9206	64.134
25.00	56.178	1640	3.498	89.81	71.84	59.5575	65.359
25.00	55.472	1920	3.518	92.49	73.41	71.3350	66.817
1.00	55.472	0	3.518	92.49	73.41	0.0000	0.000
1.00	54.893	245	3.534	94.71	74.71	55.3815	68.140
1.00	54.284	499	3.550	97.09	76.09	64.9357	69.369
1.00	53.647	713	3.567	99.62	77.53	78.9252	70.664
1.00	53.130	904	3.581	101.70	78.71	70.3856	71.869
1.00	52.476	1095	3.597	104.37	80.20	87.4324	73.027

CYCLIC CRACK GROWTH DATA

DATE- 1-17-77 I.D. NO.- A2WRDR-3
MATERIAL- AF 1410 STEEL
TEMP. & ENV.- R.T. 3.5% SALT WATER
SPECIMEN TYPE- C.T. ORIENTATION-

PLANE STRESS

E (MSI)=28.00 FTY (PSI)= 234000 NU= .30
B=1.001 P MIN (LBS)= 520.0 LF= 1000.00
W= 4.94 P MAX (LBS)= 6500.0 CM= 500 R= .080

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	62.888	42250	1.424	11.87	18.85	0.0000	0.000
30.00	62.165	54150	1.463	12.18	19.14	1.7837	17.450
30.00	61.365	82550	1.505	12.53	19.47	2.3196	17.765
30.00	60.751	96570	1.538	12.81	19.73	2.3017	18.036
30.00	60.058	110480	1.574	13.13	20.03	2.5362	18.292
1.00	60.058	0	1.574	13.13	20.03	0.0000	0.000
1.00	59.280	10000	1.613	13.49	20.37	3.9844	18.585
1.00	58.264	25320	1.664	13.97	20.81	2.7400	18.945
1.00	57.625	35348	1.696	14.29	21.11	4.0803	19.286
20.00	57.625	0	1.696	14.29	21.11	0.0000	0.000
20.00	57.057	10170	1.724	14.57	21.37	2.7482	19.542
20.00	56.416	22350	1.756	14.90	21.67	2.5646	19.796
20.00	55.863	31310	1.782	15.19	21.92	2.9799	20.050
20.00	55.230	38920	1.812	15.52	22.21	3.9242	20.301
20.00	54.473	47990	1.848	15.94	22.57	4.0011	20.601
1.00	54.473	0	1.848	15.94	22.57	0.0000	0.000
1.00	53.573	11489	1.891	16.44	23.00	3.6685	20.962
1.00	52.984	16615	1.918	16.78	23.28	5.3280	21.288
1.00	52.404	21600	1.945	17.11	23.56	5.3540	21.546
20.00	52.404	0	1.945	17.11	23.56	0.0000	0.000
20.00	52.046	6680	1.961	17.33	23.73	2.4523	21.754
20.00	51.550	12340	1.984	17.63	23.97	3.9894	21.944
20.00	51.062	18010	2.006	17.93	24.21	3.8959	22.165
20.00	50.648	22390	2.024	18.18	24.42	4.2568	22.366
20.00	50.104	26930	2.049	18.53	24.68	5.3682	22.586
1.00	50.104	0	2.049	18.53	24.68	0.0000	0.000
1.00	49.503	3538	2.075	18.92	24.99	7.5640	22.848
1.00	48.977	6509	2.099	19.27	25.25	7.5846	23.107
1.00	48.782	8300	2.107	19.40	25.35	5.0886	23.275
1.00	48.331	11258	2.127	19.71	25.58	6.7076	23.426

E (MSI)=28.00 FTY (PSI)= 234000 NU= .30
B=1.001 P MIN (LBS)= 520.0 LF= 1000.00
W= 4.94 P MAX (LBS)= 6500.0 CM= 200 R= .080

A2WKUK-J

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
25.00	70.100	0	2.148	20.04	25.82	0.0000	0.000
25.00	69.544	9330	2.185	20.65	26.27	3.9943	23.961
25.00	68.893	18740	2.228	21.37	26.79	4.5024	24.404
25.00	68.100	25930	2.277	22.27	27.42	6.9363	24.934
25.00	67.315	33060	2.325	23.18	28.05	6.6774	25.514
25.00	66.539	39200	2.371	24.10	28.67	7.4036	26.089
25.00	65.868	44780	2.409	24.91	29.21	6.8279	26.625
25.00	65.203	49880	2.445	25.72	29.75	7.1994	27.125
25.00	64.452	54360	2.486	26.66	30.37	8.9929	27.659
25.00	63.803	58570	2.520	27.49	30.92	8.0438	28.194
25.00	62.435	66550	2.588	29.28	32.09	8.6085	28.981
25.00	61.809	70160	2.619	30.12	32.63	8.3936	29.771
25.00	61.321	73020	2.642	30.79	33.07	8.0970	30.222
25.00	60.577	76200	2.676	31.82	33.74	10.8678	30.730
25.00	59.886	79100	2.708	32.80	34.38	10.8029	31.332
1.00	59.886	0	2.708	32.30	34.38	0.0000	0.000
1.00	59.205	2585	2.738	33.79	35.02	11.6775	31.920
1.00	58.617	4470	2.763	34.65	35.58	13.5489	32.474
1.00	58.036	6184	2.788	35.53	36.15	14.4568	32.994
1.00	57.544	7600	2.809	36.28	36.64	14.5776	33.480
25.00	57.544	0	2.809	36.28	36.64	0.0000	0.000
25.00	56.655	2580	2.845	37.66	37.54	14.1628	34.120
25.00	55.941	4710	2.874	38.80	38.28	13.4619	34.878
25.00	54.778	8220	2.919	40.71	39.53	12.9630	35.796
25.00	54.322	9780	2.937	41.48	40.04	11.1881	36.604
1.00	54.322	0	2.937	41.48	40.04	0.0000	0.000
1.00	53.871	1508	2.954	42.25	40.55	11.3114	37.069
1.00	53.351	2710	2.973	43.16	41.14	16.1558	37.575
1.00	52.838	3618	2.992	44.07	41.73	20.8295	38.122
1.00	52.189	4622	3.016	45.24	42.50	23.4928	38.749
20.00	52.189	0	3.016	45.24	42.50	0.0000	0.000
20.00	51.691	1190	3.034	46.15	43.10	15.0003	39.350
20.00	51.201	2190	3.051	47.07	43.71	17.3602	39.933
20.00	50.648	3190	3.070	48.12	44.40	19.3581	40.528
20.00	50.104	4310	3.089	49.17	45.09	16.7936	41.165
20.00	49.635	5190	3.105	50.10	45.70	18.2222	41.763
1.00	49.635	0	3.105	50.10	45.70	0.0000	0.000
1.00	49.107	726	3.123	51.16	46.39	24.6001	42.362
1.00	48.588	1370	3.140	52.22	47.09	26.9601	43.003
1.00	48.140	2057	3.155	53.15	47.70	21.5985	43.604
1.00	47.761	2634	3.168	53.95	48.22	21.5739	44.125

E (MSI)=28.00 FTY (PSI)= 234000 NU= .30
B=1.001 P MIN (LBS)= 520.0 LF= 1000.00
W= 4.94 P MAX (LBS)= 6500.0 CM= 100 R= .080

A2 WRDR-3

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
20.00	65.345	0	3.178	54.62	48.66	0.0000	0.000
20.00	64.452	1490	3.215	57.17	50.32	25.0323	45.533
20.00	63.711	2740	3.245	59.33	51.72	23.7649	46.940
20.00	63.069	3820	3.270	61.22	52.94	23.0418	48.146
20.00	62.345	4690	3.297	63.40	54.34	31.2306	49.351
20.00	61.631	5610	3.323	65.57	55.73	28.1756	50.631
1.00	61.631	0	3.323	65.57	55.73	0.0000	0.000
1.00	61.189	633	3.339	66.94	56.59	24.6984	51.668
1.00	60.534	1220	3.361	68.99	57.89	38.5284	52.660
1.00	59.801	1801	3.386	71.32	59.34	42.2814	53.925
1.00	59.121	2375	3.408	73.52	60.71	38.5442	55.222
20.00	59.121	0	3.408	73.52	60.71	0.0000	0.000
20.00	58.242	760	3.436	76.41	62.48	36.4553	56.666
20.00	57.625	1260	3.454	78.47	63.74	37.7582	58.060
20.00	56.815	1830	3.479	81.23	65.40	42.3034	59.401
20.00	55.981	2310	3.503	84.13	67.12	50.1550	60.956
20.00	55.394	2760	3.519	86.20	68.33	36.6910	62.307
1.00	55.394	0	3.519	86.20	68.33	0.0000	0.000
1.00	54.322	502	3.548	90.06	70.57	58.3323	63.893
1.00	53.871	763	3.560	91.72	71.52	45.9776	65.364
1.00	53.388	934	3.573	93.51	72.54	57.2473	66.268
1.00	52.765	1238	3.589	95.86	73.86	53.0881	67.342

CYCLIC CRACK GROWTH DATA

DATE- 2-12-77 I.D. NO.- A2WRDR-6
MATERIAL-AF1410 STEEL
TEMP. & ENV.- R.T. 3.5% SALT WTR
SPECIMEN TYPE- C.T. ORIENTATION-

PLANE STRESS

E (MSI)=28.00 FTY (PSI)= 234000 NU= .30
B= .998 P MIN (LBS)= 560.0 LF= 1000.00
W= 4.94 P MAX (LBS)= 7000.0 CM= 500 R= .080 1/8, 3

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
1.00	60.360	67220	1.555	13.98	21.46	0.0000	0.000
1.00	60.360	0	1.555	13.98	21.46	0.0000	0.000
1.00	59.758	4500	1.586	14.28	21.74	6.9058	19.868
1.00	59.121	13797	1.619	14.60	22.04	3.4975	20.136
1.00	58.533	18599	1.648	14.91	22.32	6.1728	20.404
1.00	58.533	0	1.648	14.91	22.32	0.0000	0.000
25.00	57.462	8410	1.702	15.47	22.84	5.3399	20.772
25.00	56.976	15570	1.725	15.73	23.08	3.3354	21.122
25.00	56.495	23150	1.749	16.00	23.32	3.0923	21.341
25.00	55.784	31500	1.783	16.40	23.67	4.1149	21.614
25.00	55.317	36730	1.806	16.66	23.91	4.2811	21.8[illegible]5
25.00	55.317	0	1.806	16.66	23.91	0.0000	0.000
1.00	54.778	4307	1.831	16.98	24.18	5.9480	22.118
1.00	54.133	10269	1.862	17.36	24.51	5.0992	22.394
1.00	53.610	13684	1.886	17.67	24.77	7.1658	22.568
25.00	53.610	0	1.886	17.67	24.77	0.0000	0.000
25.00	53.167	5580	1.907	17.94	25.00	3.6895	22.896
25.00	52.548	10810	1.935	18.33	25.32	5.4622	23.149
25.00	51.975	15290	1.962	18.70	25.62	5.8632	23.433
25.00	51.550	19790	1.981	18.97	25.84	4.2931	23.673
25.00	50.889	24900	2.011	19.41	26.19	5.8596	23.936
1.00	50.889	0	2.011	19.41	26.19	0.0000	0.000
1.00	50.375	2888	2.034	19.76	26.45	7.9977	24.222
1.00	49.970	5085	2.052	20.04	26.68	8.2590	24.447
1.00	49.569	7777	2.070	20.32	26.90	6.6334	24.646
25.00	49.569	0	2.070	20.32	26.90	0.0000	0.000
25.00	49.042	4030	2.093	20.69	27.18	5.8000	24.877
25.00	48.620	7340	2.112	21.00	27.41	5.6300	25.114
25.00	48.140	10940	2.133	21.35	27.68	5.8659	25.342
25.00	47.635	14930	2.155	21.73	27.96	5.5347	25.593
25.00	47.200	17860	2.174	22.07	28.20	6.4710	25.834
1.00	47.200	0	2.174	22.07	28.20	0.0000	0.000
1.00	46.771	1342	2.193	22.40	28.44	10.1147	26.057

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
1.00	46.289	3948	2.214	22.79	28.72	9.9247	26.295
1.00	45.872	5727	2.232	23.12	28.96	10.0933	26.533
1.00	45.696	6400	2.239	23.27	29.06	11.2965	26.690

CYCLIC CRACK GROWTH DATA

DATE- 2-12-77 I.D. NO.- A2WRDR-6
MATERIAL- AF1410
TEMP. & ENV.- RT. - 3.5% Salt Water
SPECIMEN TYPE- C.T. ORIENTATION-
PLANE STRESS

E (MSI)=28.00 FTY (PSI)= 234000 NU= .30
B= .998 P MIN (LBS)=2100.0 LF= 1000.00
W= 4.94 P MAX (LBS)= 7000.0 CM= 200 R= .300

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	68.100	9260	2.275	23.97	29.56	12.5817	23.713
30.00	67.072	19330	2.337	25.25	30.44	6.1668	20.999
30.00	66.155	28260	2.390	26.43	31.24	5.9420	21.588
30.00	65.298	36540	2.438	27.55	31.99	5.7678	22.129
1.00	64.826	0	2.464	28.18	32.41	0.0000	0.000
1.00	63.988	4882	2.508	29.32	33.16	9.0773	22.947
1.00	63.115	9204	2.553	30.54	33.95	10.3189	23.488
1.00	62.256	13827	2.595	31.76	34.75	9.1976	24.045
30.00	62.256	0	2.595	31.76	34.75	0.0000	0.000
30.00	61.321	5670	2.640	33.13	35.64	7.8936	24.635
30.00	60.708	10650	2.668	34.04	36.23	5.7464	25.154
30.00	59.886	15160	2.706	35.29	37.04	8.2874	25.647
30.00	59.121	19250	2.740	36.49	37.82	8.3003	26.203
30.00	58.492	22800	2.767	37.49	38.47	7.6814	26.702
1.00	58.492	0	2.767	37.49	38.47	0.0000	0.000
1.00	57.953	2345	2.790	38.36	39.04	9.7742	27.128
1.00	57.300	4462	2.817	39.44	39.74	12.9170	27.573
1.00	56.735	6276	2.841	40.39	40.36	12.7789	28.035
30.00	56.735	0	2.841	40.39	40.36	0.0000	0.000
30.00	56.099	2960	2.866	41.47	41.07	8.6760	28.500
30.00	55.394	5750	2.894	42.71	41.88	10.0028	29.031
30.00	54.854	8100	2.915	43.67	42.51	8.9453	29.533
30.00	54.095	10540	2.944	45.05	43.41	11.9039	30.070
30.00	53.499	12490	2.967	46.16	44.14	11.5090	30.642
1.00	53.499	0	2.967	46.16	44.14	0.0000	0.000
1.00	52.765	1513	2.994	47.55	45.05	17.9206	31.217
1.00	52.476	2676	3.004	48.11	45.42	9.0848	31.666
1.00	52.010	3657	3.021	49.02	46.02	17.1671	32.004
1.00	51.410	4781	3.043	50.22	46.81	19.0668	32.489
30.00	51.410	0	3.043	50.22	46.81	0.0000	0.000
30.00	50.854	1670	3.062	51.34	47.55	11.7266	33.024
30.00	50.104	3190	3.088	52.90	48.57	17.1335	33.642

A2WRDR-6

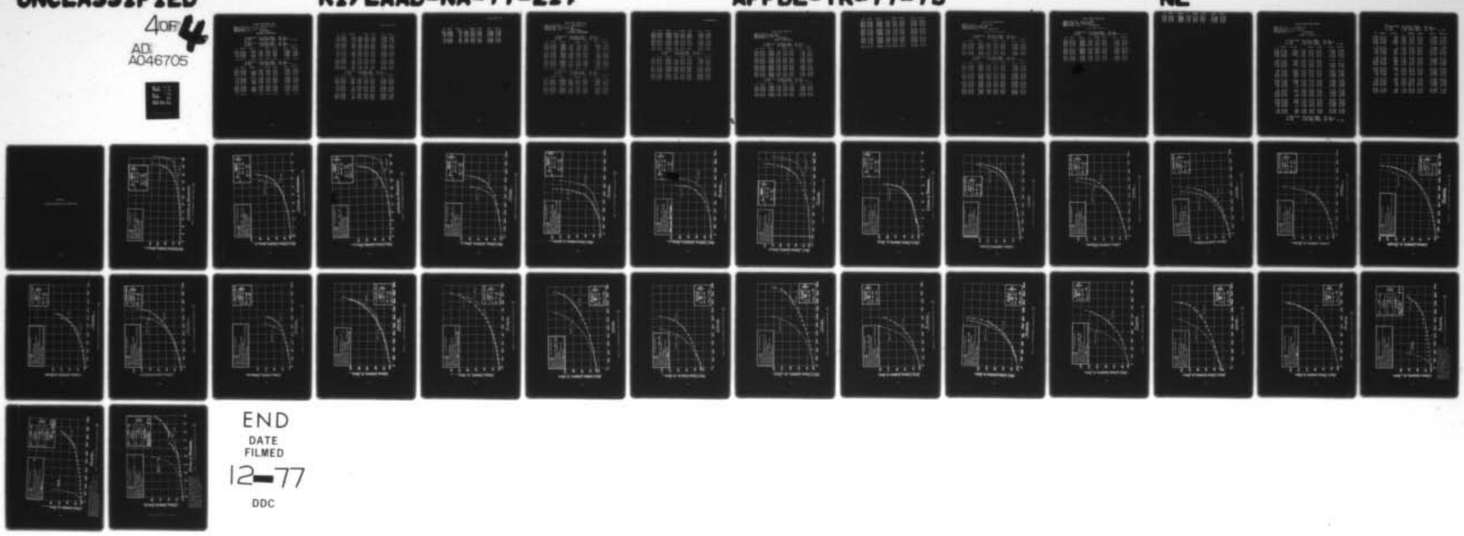
HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	49.602	4500	3.105	53.97	49.27	13.1273	34.246
30.00	49.107	5760	3.122	55.04	49.98	13.3040	34.737
30.00	48.459	6870	3.144	56.47	50.91	19.5538	35.311
1.00	48.459	0	3.144	56.47	50.91	0.0000	0.000
1.00	48.013	907	3.159	57.47	51.57	16.2865	35.862
1.00	47.510	1655	3.175	58.62	52.32	22.0250	36.363
1.00	46.893	2427	3.195	60.06	53.26	25.9155	36.955
1.00	46.409	3147	3.211	61.22	54.02	21.6050	37.548

E (MSI)=28.00 FTY (PSI)= 234000 NU= .30
B= .998 P MIN (LBS)=2100.0 LF= 1000.00
W= 4.94 P MAX (LBS)= 7000.0 CM= 100 R= .300

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	64.546	0	3.211	61.22	54.02	0.0000	0.000
30.00	63.711	1590	3.244	63.83	55.71	19.8932	38.405
30.00	62.978	3130	3.273	66.16	57.22	19.7088	39.524
30.00	62.211	4500	3.301	68.64	58.81	20.9635	40.600
30.00	61.542	5700	3.326	70.84	60.21	20.1651	41.657
30.00	60.751	6670	3.353	73.49	61.89	28.5794	42.734
1.00	60.751	0	3.353	73.49	61.89	0.0000	0.000
1.00	60.317	675	3.368	74.96	62.81	21.9518	43.645
1.00	59.630	1282	3.391	77.32	64.29	37.7135	44.485
1.00	58.952	1905	3.413	79.69	65.75	35.2220	45.515
1.00	58.367	2411	3.431	81.76	67.03	36.4984	46.474
1.00	57.953	2935	3.444	83.24	67.93	24.3704	47.225
1.00	57.381	3376	3.462	85.32	69.19	39.5061	47.993
30.00	57.381	0	3.462	85.32	69.19	0.0000	0.000
30.00	56.495	660	3.488	88.59	71.15	39.6017	49.120
30.00	55.628	1260	3.513	91.85	73.09	41.3257	50.483
30.00	55.008	1750	3.530	94.23	74.48	35.2021	51.647
30.00	54.246	2250	3.550	97.20	76.19	41.3877	52.735
30.00	53.721	2610	3.564	99.28	77.38	38.7340	53.753
1.00	53.721	0	3.564	99.28	77.38	0.0000	0.000
1.00	53.093	328	3.581	101.80	78.81	49.8974	54.669
1.00	52.584	613	3.594	103.86	79.98	45.7358	55.577
1.00	52.117	887	3.606	105.81	81.05	42.9263	56.360
1.00	51.410	1154	3.623	108.77	82.68	65.4822	57.304
1.00	50.766	1396	3.638	111.43	84.12	62.5410	58.380

AD-A046 705 ROCKWELL INTERNATIONAL LOS ANGELES CALIF LOS ANGELE--ETC F/G 1/3
LOWER COST BY SUBSTITUTING STEEL FOR TITANIUM. AF1410 STEEL-DET--ETC(U)
JUN 77 W E ROUTH F33615-75-C-3109
UNCLASSIFIED RI/LAAD-NA-77-217 AFFDL-TR-77-73 NL

4 OF 4
AD A046705



END
DATE
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12-77
DDC

CYCLIC CRACK GROWTH DATA

DATE- 1-8-77 I.D. NO.- A2RWDR-2
MATERIAL- AF1410
TEMP. & ENV.- R.T. - SUMP WATER
SPECIMEN TYPE- C.T. ORIENTATION-

PLANE STRESS

E (MSI)=28.00 FTY (PSI)= 234000 NU= .30
B= .997 P MIN (LBS)= 448.0 LF= 1000.00
W= 4.94 P MAX (LBS)= 5600.0 CM= 500 R= .080
W=
E (MSI)=28.00 FTY (PSI)= 234000 NU= .30
B= .997 P MIN (LBS)= 448.0 LF= 1000.00
W= 4.94 P MAX (LBS)= 5600.0 CM= 500 R= .080

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	62.616	61860	1.434	10.33	16.37	23.1838	7.528
30.00	61.365	98450	1.501	10.80	16.81	1.8296	15.259
1.00	61.454	0	1.496	10.76	16.77	0.0000	0.000
1.00	58.952	50390	1.626	11.75	17.70	2.5693	15.859
1.00	57.057	95390	1.720	12.55	18.44	2.0968	16.625
1.00	55.162	121218	1.812	13.40	19.20	3.5433	17.311

E (MSI)=28.00 FTY (PSI)= 234000 NU= .30
B= .997 P MIN (LBS)= 448.0 LF= 1000.00
W= 4.94 P MAX (LBS)= 5600.0 CM= 200 R= .080

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	74.570	0	1.801	13.30	19.10	0.0000	0.000
30.00	73.196	27790	1.916	14.47	20.10	4.1365	18.033
30.00	71.841	63770	2.020	15.66	21.06	2.9122	18.936
30.00	71.119	79530	2.073	16.31	21.57	3.3432	19.612
30.00	70.100	94640	2.144	17.25	22.28	4.7117	20.170
30.00	69.494	105950	2.185	17.83	22.70	3.5886	20.688
1.00	69.494	0	2.185	17.83	22.70	0.0000	0.000
1.00	67.805	15375	2.292	19.47	23.86	6.9731	21.415
1.00	66.155	30672	2.389	21.14	25.00	6.3444	22.475
1.00	64.733	41204	2.467	22.65	26.00	7.4392	23.461
30.00	64.733	0	2.467	22.65	26.00	0.0000	0.000
30.00	63.069	13430	2.554	24.48	27.20	6.4182	24.475
30.00	62.076	20290	2.603	25.61	27.94	7.1351	25.368
30.00	61.277	26690	2.641	26.55	28.55	5.9595	25.989
30.00	60.317	32010	2.685	27.70	29.30	8.3579	26.614
1.00	60.317	0	2.685	27.70	29.30	0.0000	0.000

A2R WOR-2

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
1.00	58.868	6487	2.750	29.51	30.47	9.9357	27.497
1.00	57.381	11982	2.813	31.44	31.73	11.4965	28.614
1.00	55.981	16434	2.870	33.34	32.97	12.7970	29.764
30.00	55.981	0	2.870	33.34	32.97	0.0000	0.000
30.00	55.394	2260	2.893	34.16	33.51	10.2630	30.581
30.00	54.778	4520	2.917	35.04	34.08	10.6135	31.093
30.00	54.095	6840	2.943	36.03	34.74	11.2499	31.658
30.00	53.499	8900	2.966	36.92	35.32	10.8988	32.226
30.00	52.911	10860	2.987	37.81	35.90	11.1127	32.763
1.00	52.911	0	2.987	37.81	35.90	0.0000	0.000
1.00	52.189	1333	3.014	38.93	36.64	19.7520	33.370
1.00	51.621	2648	3.034	39.83	37.23	15.4985	33.980
1.00	51.062	3965	3.054	40.73	37.82	15.0359	34.525
1.00	50.443	5170	3.075	41.75	38.49	17.9396	35.106
1.00	49.903	6280	3.094	42.66	39.09	16.8055	35.683
1.00	49.304	7375	3.115	43.68	39.76	18.6145	36.272
30.00	49.304	0	3.115	43.68	39.76	0.0000	0.000
30.00	48.652	1370	3.136	44.82	40.51	16.0097	36.927
30.00	48.140	2560	3.153	45.74	41.11	14.3106	37.546
30.00	47.635	3620	3.170	46.66	41.71	15.6507	38.101
30.00	47.139	4670	3.186	47.58	42.32	15.3971	38.655
30.00	46.459	5760	3.208	48.85	43.15	19.7882	39.313
30.00	45.813	6830	3.229	50.13	43.97	19.4768	40.075

E (MSI)=28.00 FTY (PSI)= 234000 NU= .30
B= .997 P MIN (LBS)= 448.0 LF= 1000.00
W= 4.94 P MAX (LBS)= 5600.0 CM= 100 R= .080

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	62.978	9060	3.272	52.92	45.78	19.3340	41.287
30.00	62.166	10400	3.302	55.03	47.13	22.6726	42.738
30.00	61.454	11640	3.328	56.90	48.33	20.7382	43.910
30.00	60.664	12900	3.355	59.02	49.67	21.8914	45.076
30.00	59.972	13970	3.379	60.91	50.85	21.8717	46.237
1.00	59.972	0	3.379	60.91	50.85	0.0000	0.000
1.00	59.290	725	3.401	62.80	52.03	30.9274	47.323
1.00	58.533	1532	3.425	64.93	53.34	29.9000	48.469
1.00	57.871	2185	3.446	66.82	54.50	31.4485	49.607
1.00	57.138	2886	3.468	68.96	55.79	31.5871	50.734
1.00	56.336	3446	3.492	71.34	57.21	41.9431	51.983
30.00	56.336	0	3.492	71.34	57.21	0.0000	0.000
30.00	55.667	770	3.511	73.36	58.41	24.8083	53.187
30.00	55.008	1290	3.529	75.38	59.59	35.3066	54.281
30.00	54.246	1840	3.550	77.75	60.97	37.6480	55.458

A2RWDR-2

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	53.721	2250	3.564	79.42	61.92	34.0312	56.528
30.00	52.838	2800	3.587	82.27	63.53	41.7211	57.707
1.00	52.838	0	3.587	82.27	63.53	0.0000	0.000
1.00	52.189	351	3.603	84.40	64.72	46.8718	58.996
1.00	51.550	674	3.619	86.54	65.90	49.0499	60.085
1.00	50.923	932	3.634	88.67	67.06	49.5715	61.159
1.00	50.307	1256	3.649	90.79	68.20	53.7382	62.219
1.00	49.635	1519	3.665	93.15	69.45	59.9161	63.322
1.00	48.977	1814	3.680	95.51	70.69	51.3886	64.456

CYCLIC CRACK GROWTH DATA

DATE- 2-12-77 I.D. NO.- A2WRDO-1
MATERIAL- AF1410
TEMP. & ENV.- -65°, LAB AIR
SPECIMEN TYPE- C.T. ORIENTATION-

PLANE STRESS

E (MSI)=30.60 FTY (PSI)= 240000 NU= .30
B= .998 P MIN (LBS)= 320.0 LF= 1000.00
W= 4.94 P MAX (LBS)= 4000.0 CM= 500 R= .080

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	58.617	507680	1.758	9.20	13.38	0.0000	0.000
30.00	58.617	507680	1.758	9.20	13.38	0.0000	0.000
30.00	57.625	586050	1.807	9.53	13.67	.6304	12.441
30.00	56.815	650260	1.847	9.81	13.91	.6185	12.668
30.00	55.863	703630	1.893	10.15	14.20	.8619	12.931
30.00	54.816	767170	1.943	10.53	14.52	.7824	13.210
30.00	53.945	825000	1.983	10.86	14.78	.7046	13.479
30.00	52.964	887310	2.028	11.24	15.08	.7125	13.738
30.00	51.975	934100	2.074	11.65	15.40	.9820	14.020
30.00	51.270	967000	2.105	11.94	15.62	.9635	14.267
30.00	50.307	1009730	2.148	12.35	15.93	1.0040	14.511
30.00	49.569	1044280	2.181	12.68	16.17	.9424	14.763
30.00	48.912	1074230	2.210	12.98	16.38	.9604	14.972
30.00	47.510	1128220	2.270	13.64	16.85	1.1233	15.267
30.00	46.110	1175710	2.330	14.34	17.34	1.2595	15.725
30.00	44.772	1222470	2.387	15.05	17.82	1.2075	16.171

E (MSI)=30.60 FTY (PSI)= 240000 NU= .30
B= .998 P MIN (LBS)= 320.0 LF= 1000.00
W= 4.94 P MAX (LBS)= 4000.0 CM= 200 R= .080

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	68.051	1222470	2.386	15.05	17.81	0.0000	0.000
30.00	66.732	1275550	2.463	15.10	18.52	1.4586	16.711
30.00	65.677	1317100	2.522	16.97	19.09	1.4139	17.298
30.00	64.359	1359170	2.592	18.10	19.82	1.6577	17.899
30.00	63.252	1386890	2.648	19.07	20.45	2.0110	18.528
30.00	62.255	1411560	2.696	19.97	21.04	1.9517	19.089
30.00	61.277	1433530	2.741	20.88	21.63	2.0741	19.631
30.00	60.144	1455000	2.792	21.97	22.34	2.3666	20.228
30.00	59.374	1468290	2.826	22.73	22.83	2.5130	20.730
30.00	58.367	1483310	2.868	23.75	23.50	2.8259	21.313

A2WRDO-1

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	57.300	1496650	2.912	24.86	24.23	3.2606	21.954
30.00	56.336	1508830	2.950	25.89	24.91	3.1231	22.601
30.00	55.472	1518330	2.983	26.85	25.53	3.4974	23.201
30.00	54.473	1527470	3.020	27.98	26.28	4.0906	23.833
30.00	53.573	1535560	3.053	29.04	26.97	4.0598	24.405
30.00	53.057	1541710	3.072	29.66	27.38	3.0012	25.001
30.00	52.117	1548620	3.105	30.81	28.14	4.7757	25.537
30.00	50.240	1561150	3.168	33.22	29.72	5.0623	26.613
30.00	48.749	1571080	3.217	35.25	31.04	4.8044	27.948
30.00	47.262	1579750	3.264	37.38	32.42	5.4155	29.192
30.00	45.991	1586340	3.303	39.30	33.65	5.9209	30.393
30.00	44.451	1592610	3.348	41.73	35.19	7.2902	31.660

E (MSI)=30.60　FTY (PSI)= 240000　NU= .30
B= .998　P MIN (LBS)= 320.0　LF= 1000.00
W= 4.94　P MAX (LBS)= 4000.0　CM= 100　R= .080

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	62.797	1592610	3.356	42.14	35.46	0.0000	0.000
30.00	61.542	1598800	3.400	44.72	37.07	7.0935	33.361
30.00	60.317	1603760	3.440	47.31	38.66	8.1696	34.835
30.00	58.866	1608480	3.486	50.46	40.56	9.5754	36.442
30.00	57.912	1611970	3.514	52.59	41.82	8.1244	37.897
30.00	56.735	1614970	3.547	55.28	43.39	11.1571	39.198
30.00	55.472	1617840	3.582	58.25	45.08	11.9439	40.695
30.00	54.511	1620040	3.607	60.55	45.37	11.3801	42.067
30.00	53.462	1621970	3.633	63.15	47.79	13.6776	43.312
30.00	52.260	1623770	3.662	66.20	49.42	16.1618	44.712
30.00	51.305	1625310	3.684	68.68	50.71	14.4981	46.060
30.00	49.970	1626950	3.715	72.25	52.54	18.3797	47.497
30.00	49.272	1627950	3.730	74.17	53.50	15.1371	48.776
30.00	48.257	1629000	3.751	76.98	54.88	20.6437	49.952
30.00	47.386	1629740	3.770	79.52	56.09	24.7980	51.047

D1

CYCLIC CRACK GROWTH DATA

DATE- 3-2-77 I.D. NO.- D1
MATERIAL-AF1410 STEEL WELD
TEMP. & ENV.- R.T. - LAB AIR
SPECIMEN TYPE- C.T. ORIENTATION-
PLANE STRESS

E (MSI)=28.00 FTY (PSI)= 234000 NU= .30
B= .595 P MIN (LBS)= 360.0 LF= 1000.00
W= 5.00 P MAX (LBS)= 4500.0 CM= 200 R= .080

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	66.926	957910	1.941	19.35	24.22	0.0000	0.000
30.00	65.582	1030230	2.022	20.56	25.21	1.1175	22.736
30.00	64.173	1110670	2.102	21.85	26.24	.9924	23.665
30.00	62.888	1189720	2.171	23.06	27.19	.8728	24.578
30.00	61.101	1239260	2.261	24.80	28.51	1.8234	25.624
30.00	59.459	1273030	2.340	26.46	29.74	2.3255	26.798
30.00	58.036	1301070	2.405	27.95	30.82	2.3145	27.859
30.00	56.815	1318910	2.458	29.26	31.76	3.0018	28.785
30.00	55.317	1333990	2.522	30.94	32.92	4.2038	29.751
30.00	54.246	1345740	2.566	32.18	33.77	3.7325	30.678
30.00	53.057	1355220	2.613	33.60	34.73	5.0053	31.509
30.00	51.975	1364110	2.655	34.94	35.62	4.7380	32.360
30.00	50.993	1371170	2.693	36.19	36.44	5.3008	33.140
30.00	49.970	1377090	2.731	37.54	37.32	6.4583	33.932
30.00	48.912	1382580	2.770	38.97	38.25	7.0717	34.765
30.00	47.386	1387150	2.824	41.14	39.64	11.9891	35.833
30.00	47.139	1391250	2.833	41.51	39.87	2.1363	36.578
30.00	45.172	1398800	2.902	44.51	41.77	9.0329	37.557
30.00	44.433	1401580	2.927	45.69	42.52	9.1171	38.773

E (MSI)=28.00 FTY (PSI)= 234000 NU= .30
B= .595 P MIN (LBS)= 360.0 LF= 1000.00
W= 5.00 P MAX (LBS)= 4500.0 CM= 100 R= .080

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	62.797	1401580	2.935	46.06	42.75	0.0000	0.000
30.00	61.277	1406920	2.996	49.18	44.69	11.5532	40.222
30.00	59.843	1411050	3.052	52.23	46.58	13.3349	41.985
30.00	58.826	1414200	3.089	54.46	47.95	11.8808	43.494
30.00	57.666	1417010	3.130	57.06	49.56	14.6458	44.854
30.00	56.575	1419140	3.167	59.59	51.10	17.5420	46.303
30.00	55.472	1421270	3.204	62.22	52.71	17.1675	47.755
30.00	54.322	1423090	3.241	65.05	54.44	20.2959	49.289

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	53.351	1424710	3.271	67.51	55.94	18.7075	50.773
30.00	52.260	1426100	3.304	70.36	57.67	23.8615	52.259
30.00	51.270	1427250	3.334	73.03	59.29	25.5280	53.801
30.00	50.104	1428350	3.368	76.29	61.26	30.6825	55.453
30.00	49.239	1429220	3.392	78.78	62.77	28.1808	57.053
30.00	48.459	1430000	3.414	81.09	64.16	27.8348	58.388
30.00	47.573	1430660	3.438	83.79	65.79	36.7995	59.778
30.00	45.696	1432030	3.488	89.80	69.40	36.6092	62.185
30.00	44.209	1433010	3.527	94.86	72.43	39.4236	65.239
30.00	42.350	1433780	3.561	99.74	75.34	44.8761	67.970
30.00	41.457	1434450	3.596	105.03	78.47	51.9031	70.753
30.00	40.089	1435020	3.630	110.53	81.72	58.8959	73.692
30.00	38.660	1435550	3.664	116.64	85.31	65.1642	75.838
30.00	37.718	1435910	3.687	120.89	87.79	62.4734	79.630
30.00	36.692	1436240	3.711	125.73	90.61	73.6440	82.068
30.00	35.810	1436510	3.732	130.08	93.14	76.7176	84.525
30.00	34.118	1436930	3.771	139.00	98.27	93.8756	88.045

CYCLIC CRACK GROWTH DATA

DATE- 3-2-77 I.D. NO.- D2
MATERIAL- AF1410 STEEL WELD
TEMP. & ENV.- R.T. - LAB AIR
SPECIMEN TYPE- C.T. ORIENTATION-

E (MSI)=28.00 FTY (PSI)= 234000 NU= .30
B= .595 P MIN (LBS)= 320.0 LF= 1000.00
W= 5.01 P MAX (LBS)= 4000.0 CM= 200 R= .080

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	51.621	782400	2.674	31.39	31.89	0.0000	0.000
30.00	50.511	792070	2.716	32.66	32.73	4.3447	29.725
30.00	49.304	801340	2.761	34.10	33.66	4.8264	30.538
30.00	48.331	808790	2.795	35.30	34.43	4.7535	31.323
30.00	47.355	815230	2.831	36.54	35.23	5.4271	32.044
30.00	46.289	821160	2.869	37.95	36.12	6.3417	32.822
30.00	45.172	826990	2.908	39.46	37.09	6.6519	33.680
30.00	44.209	831800	2.941	40.86	37.96	6.8679	34.524

E (MSI)=28.00 FTY (PSI)= 234000 NU= .30
B= .595 P MIN (LBS)= 320.0 LF= 1000.00
W= 5.01 P MAX (LBS)= 4000.0 CM= 100 R= .080

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	62.706	831800	2.944	41.02	38.06	0.0000	0.000
30.00	60.926	840760	3.016	44.28	40.09	8.0153	35.950
30.00	59.290	847220	3.078	47.40	42.02	9.5923	37.773
30.00	57.953	852090	3.126	50.04	43.65	9.8760	39.409
30.00	56.735	856760	3.168	52.53	45.18	9.0145	40.860
30.00	55.162	860930	3.221	55.87	47.22	12.5035	42.501
30.00	53.833	864190	3.263	58.80	49.01	12.9752	44.263
30.00	52.693	866450	3.298	61.41	50.60	15.5556	45.817
30.00	51.410	869060	3.336	64.45	52.44	14.7032	47.395
30.00	50.307	870690	3.368	67.17	54.09	19.6972	49.005
30.00	49.173	872380	3.401	70.06	55.84	19.0749	50.568
30.00	48.103	874210	3.430	72.88	57.54	16.1746	52.157
30.00	47.386	875740	3.450	74.85	58.73	12.8898	53.487
30.00	45.462	878510	3.501	80.35	62.04	18.5299	55.554
30.00	44.829	879490	3.518	82.25	63.18	16.8784	57.599
30.00	43.603	881160	3.549	86.06	65.45	18.8048	59.168
30.00	41.811	883120	3.595	91.96	68.96	23.0314	61.830
30.00	41.058	883801	3.613	94.57	70.51	27.3919	64.158
30.00	39.525	884950	3.651	100.15	73.81	32.6275	66.336

CYCLIC CRACK GROWTH DATA

DATE- 3-2-77 I.D. NO.- D2
MATERIAL- AF1410 STEEL - WELD
TEMP. & ENV.- R.T. - LAB AIR
SPECIMEN TYPE- C.T. ORIENTATION-

E (MSI)=28.00 FTY (PSI)= 234000 NU= .30
B= .595 P MIN (LBS)= 320.0 LF= 1000.00
W= 5.01 P MAX (LBS)= 4000.0 CM= 200 R= .080

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K	
30.00	69.796	217560	1.754	14.96	19.66	0.0000	0.000	
30.00	68.100	342700	1.870	16.25	20.75	.9307	18.556	
30.00	66.155	437170	1.992	17.78	22.01	1.2919	19.668	
30.00	64.452	517290	2.091	19.15	23.12	1.2283	20.759	
30.00	62.797	603660	2.180	20.54	24.20	1.0348	21.769	
30.00	62.797	603660	2.180	20.54	24.20	1.0348	21.769	
30.00	61.014	626510	2.270	22.08	25.38	3.9530	22.809	X
30.00	60.015	660000	2.318	22.97	26.04	1.4394	23.653	
30.00	58.284	698400	2.399	24.56	27.20	2.0849	24.491	
30.00	56.976	723370	2.456	25.80	28.09	2.3159	25.433	
30.00	55.394	744270	2.524	27.37	29.18	3.2181	26.344	
30.00	54.096	759000	2.577	28.70	30.09	3.6161	27.266	
30.00	52.802	771940	2.628	30.08	31.02	3.9797	28.114	
30.00	51.656	782400	2.673	31.35	31.87	4.2453	28.929	

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	38.217	885730	3.682	105.22	76.78	40.4126	69.272
30.00	36.692	886630	3.719	111.53	80.46	40.2926	72.334
30.00	35.078	887480	3.756	118.74	84.63	44.5842	75.845
30.00	33.585	888080	3.791	125.94	88.77	57.8874	79.765
30.00	32.297	888570	3.821	132.63	92.57	60.6407	83.419

CYCLIC CRACK GROWTH DATA

DATE- 3-2-77 I.D. NO.- D3
MATERIAL- AF1410 STEEL - WELD
TEMP. & ENV.- R.T. - SALT WATER
SPECIMEN TYPE- C.T. ORIENTATION-
PLANE STRESS

E (MSI)=28.00 FTY (PSI)= 234000 NU= .30
B= .584 P MIN (LBS)= 400.0 LF= 1000.00
W= 5.00 P MAX (LBS)= 5000.0 CM= 200 R= .080

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	68.893	67970	1.789	19.61	25.50	0.0000	0.000
30.00	67.510	95930	1.881	20.94	26.62	3.2788	23.975
30.00	66.347	118230	1.954	22.09	27.57	3.2535	24.927
30.00	65.203	138290	2.021	23.24	28.51	3.3738	25.795
1.00	65.203	0	2.021	23.24	28.51	0.0000	0.000
1.00	64.173	12250	2.080	24.29	29.35	4.7526	26.615
30.00	63.024	15180	2.142	25.49	30.30		
30.00	61.809	29830	2.205	26.79	31.31	4.2944	28.339
30.00	60.664	43560	2.261	28.04	32.26	4.1402	29.240
1.00	60.664	0	2.261	28.04	32.26	0.0000	0.000
1.00	59.417	10446	2.321	29.45	33.30	5.6987	30.158
1.00	58.450	19314	2.366	30.56	34.12	5.0276	31.015
1.00	57.707	25900	2.399	31.44	34.75	5.0723	31.681
30.00	56.456	11460	2.454	32.95	35.83	0.0000	0.000
30.00	55.667	18700	2.487	33.93	36.51	4.6356	33.276
30.00	54.702	25070	2.527	35.16	37.36	6.3086	33.982
30.00	53.945	30680	2.558	36.14	38.03	5.4955	34.682
30.00	53.204	35500	2.588	37.13	38.70	6.1689	35.299
1.00	53.204	0	2.588	37.13	38.70	0.0000	0.000
1.00	52.046	3976	2.633	38.71	39.76	11.4324	36.094
1.00	51.410	7128	2.658	39.60	40.36	7.7723	36.855
1.00	50.717	10127	2.684	40.59	41.01	8.7945	37.429
30.00	50.717	0	2.684	40.59	41.01	0.0000	0.000
30.00	49.970	3730	2.712	41.69	41.73	7.5173	38.060
30.00	49.173	7050	2.742	42.88	42.51	8.8836	38.748
30.00	48.395	9670	2.770	44.08	43.28	10.8471	39.463
30.00	47.604	12300	2.799	45.33	44.09	10.8481	40.190
30.00	46.955	14590	2.822	46.39	44.76	10.1168	40.871
1.00	46.955	0	2.822	46.39	44.76	0.0000	0.000
1.00	46.169	1711	2.850	47.70	45.59	16.2076	41.564
1.00	45.491	3299	2.873	48.86	46.33	14.9250	42.285
1.00	44.971	4668	2.891	49.77	46.90	13.1718	42.888
1.00	44.321	6134	2.914	50.93	47.64	15.2884	43.489

E (MSI)=28.00 FTY (PSI)= 234000 NU= .30
B= .584 P MIN (LBS)= 400.0 LF= 1000.00
W= 5.00 P MAX (LBS)= 5000.0 CM= 100 R= .080

W=
E (MSI)=28.00 FTY (PSI)= 234000 NU= .30
B= .584 P MIN (LBS)= 400.0 LF= 1000.00
W= 5.00 P MAX (LBS)= 5000.0 CM= 100 R= .080

HZ	THETA	CYCLES	A	STRESS	K-MAX	DA/DN	DELTA K
30.00	61.631	3540	2.966	53.78	49.42	0.0000	0.000
30.00	60.577	6190	3.007	56.23	50.94	15.6948	46.167
30.00	59.544	8450	3.047	58.70	52.47	17.3622	47.570
30.00	58.784	10290	3.075	60.55	53.61	15.2252	48.797
30.00	57.871	12110	3.107	62.82	55.01	17.9792	49.966
1.00	57.871	0	3.107	62.82	55.01	0.0000	0.000
1.00	56.815	1286	3.144	65.52	56.67	28.5280	51.371
1.00	55.941	2441	3.173	67.80	58.07	25.5392	52.777
1.00	55.085	3462	3.202	70.10	59.47	27.6113	54.068
1.00	54.322	4431	3.226	72.19	60.75	25.3587	55.301
1.00	53.499	5205	3.252	74.50	62.16	33.5224	56.537
1.00	52.620	6031	3.279	77.03	63.69	32.8053	57.891
30.00	51.727	1000	3.306	79.67	65.30	0.0000	0.000
30.00	50.993	1670	3.328	81.89	66.65	32.4565	60.695
30.00	50.307	2300	3.348	84.01	67.93	31.7144	61.908
30.00	49.635	2840	3.367	86.14	69.22	35.7[illegible]43	63.092
30.00	48.652	3480	3.395	89.34	71.16	43.4[illegible]31	64.574
1.00	48.652	0	3.395	89.34	71.16	0.0000	0.000
1.00	47.823	473	3.418	92.12	72.83	48.6283	66.235
1.00	47.200	868	3.435	94.26	74.13	43.1866	67.601
1.00	46.529	1205	3.453	96.62	75.55	53.8964	68.849
1.00	45.813	1550	3.472	99.20	77.10	55.4603	70.216
1.00	45.259	1796	3.487	101.25	78.33	59.6338	71.495
30.00	44.489	390	3.507	104.17	80.07	0.0000	0.000
30.00	43.877	700	3.523	106.55	81.50	51.1642	74.321
30.00	43.170	990	3.541	109.36	83.18	62.5040	75.749
30.00	42.430	1280	3.560	112.40	84.99	64.8696	77.355
30.00	41.811	1490	3.576	115.01	86.54	74.1537	78.901

APPENDIX E

FRACTURE MECHANICS CRACK GROWTH TESTS

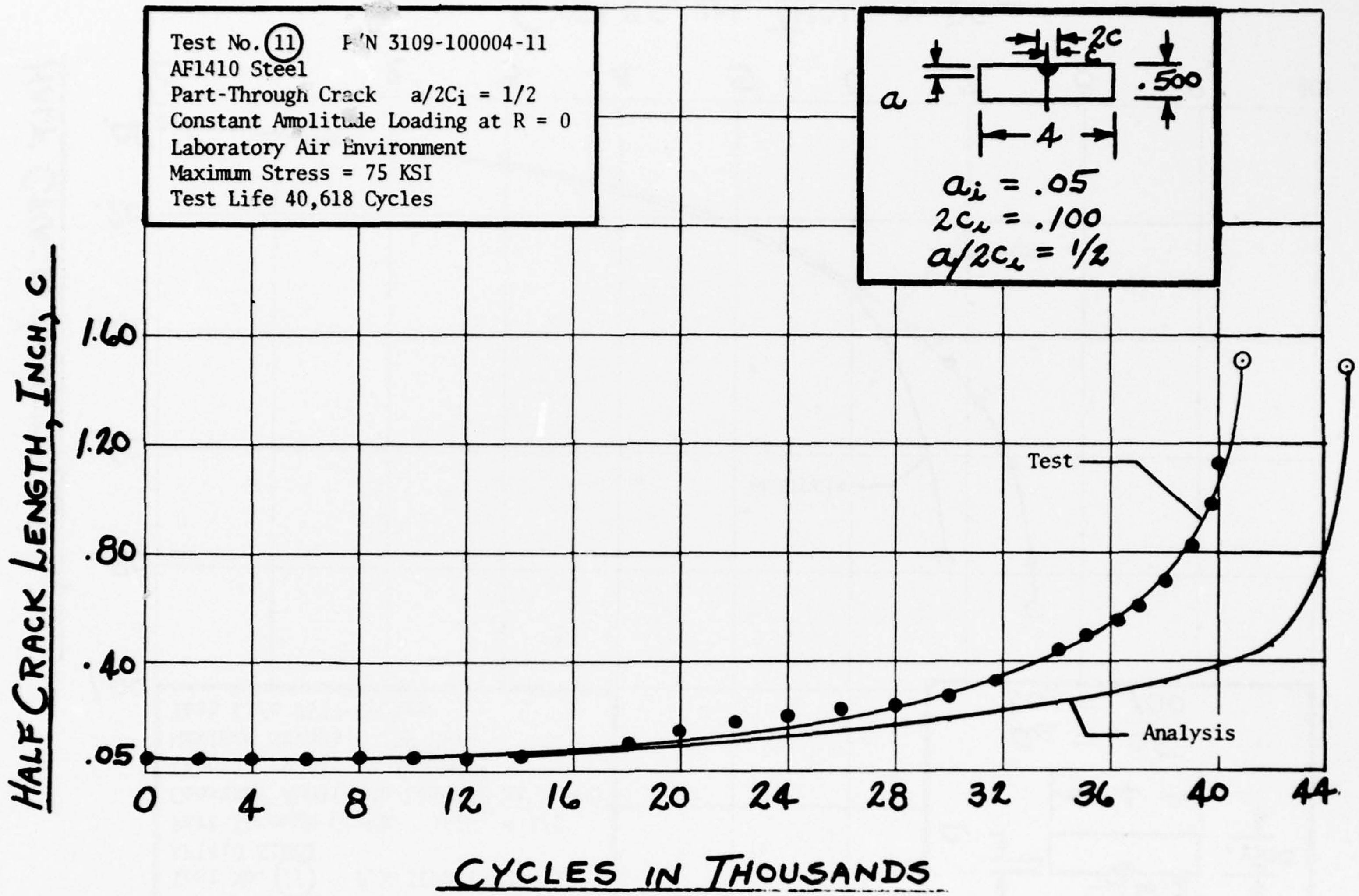


Figure E-1 Fracture Mechanics Crack Growth Test (11)

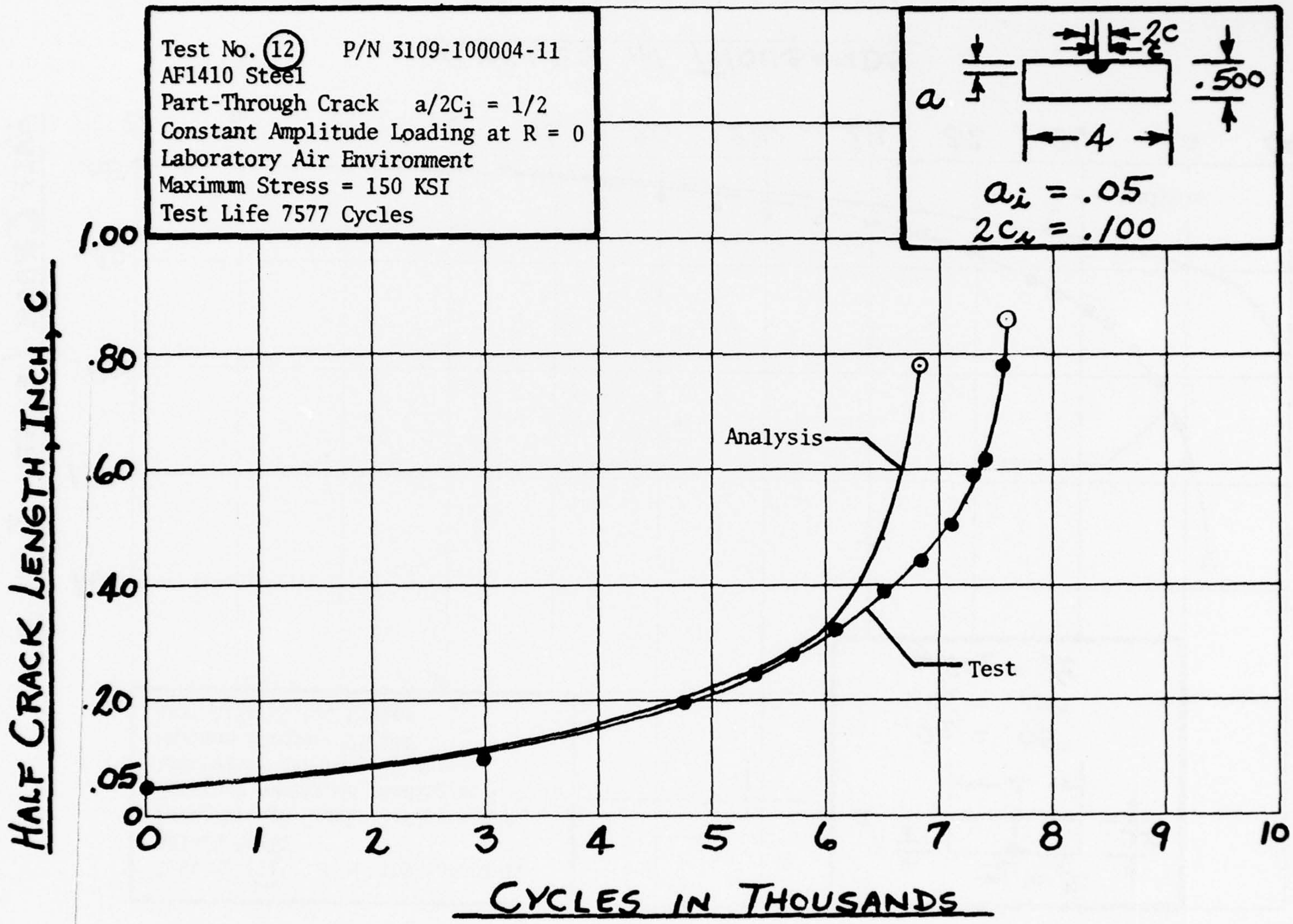


Figure E-2 Fracture Mechanics Crack Growth Test (12)

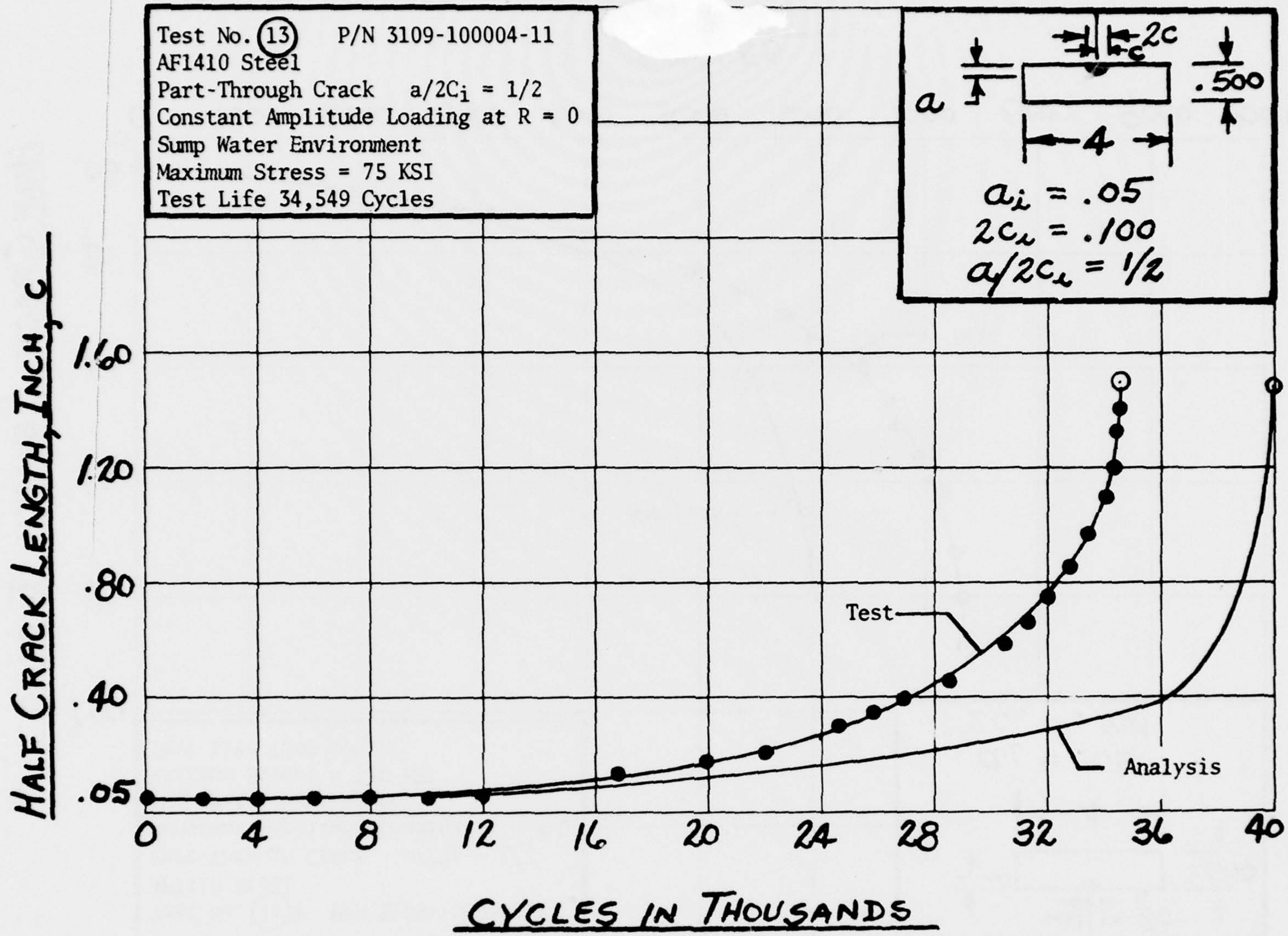


Figure E-3 Fracture Mechanics Crack Growth Test 13

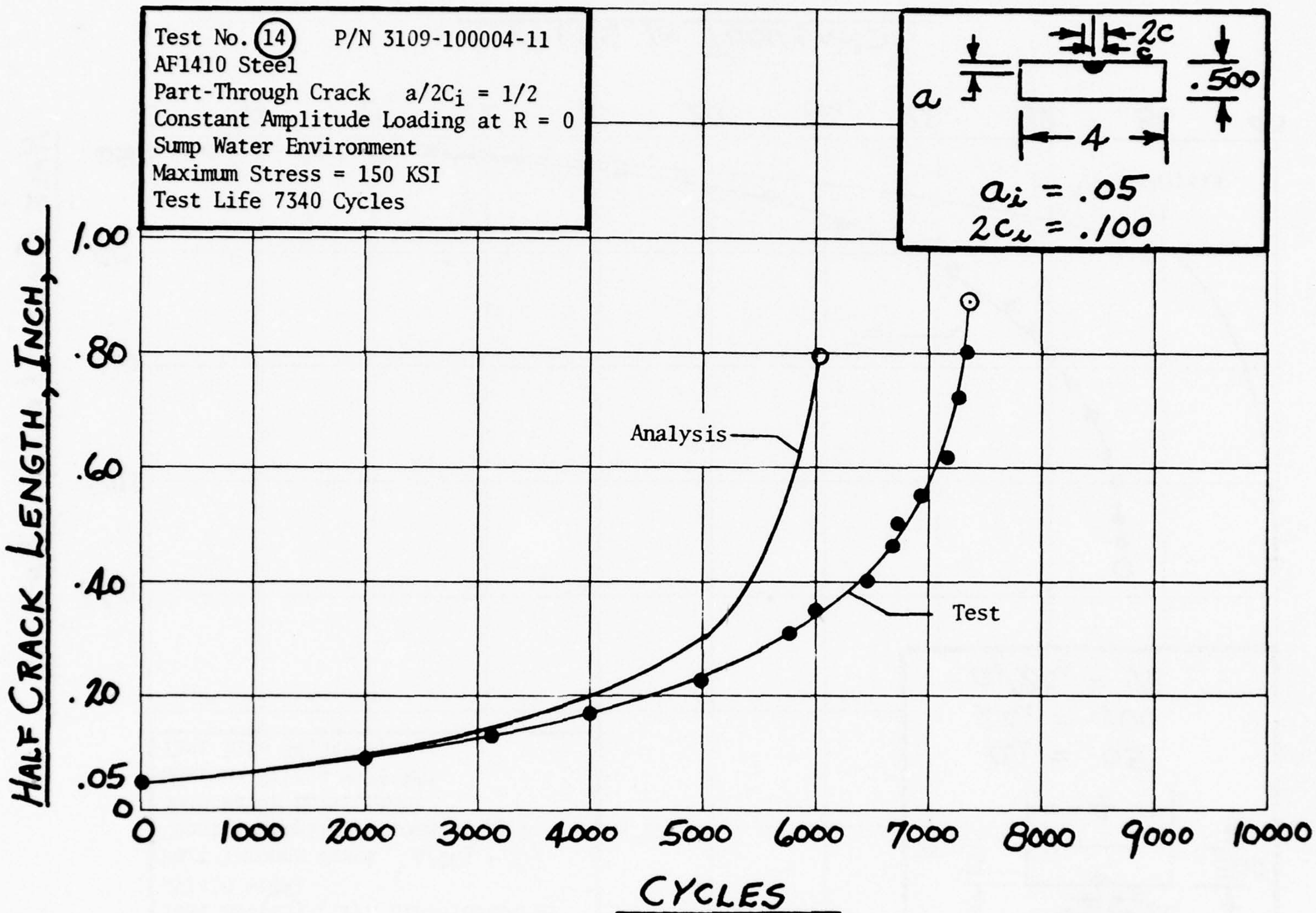


Figure E-4. Fracture Mechanics Crack Growth Test (14)

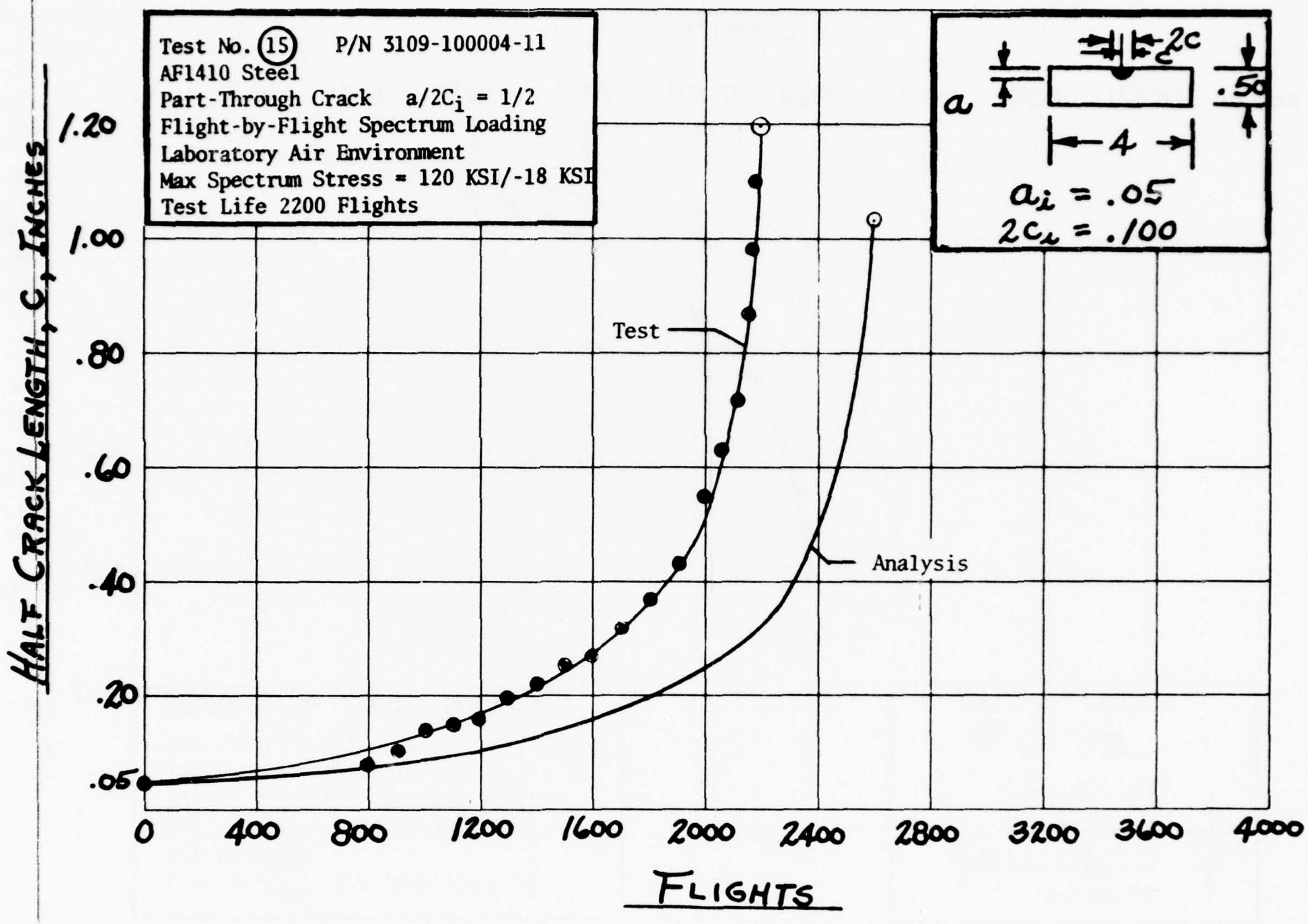


Figure E-5 Fracture Mechanics Crack Growth Test 15

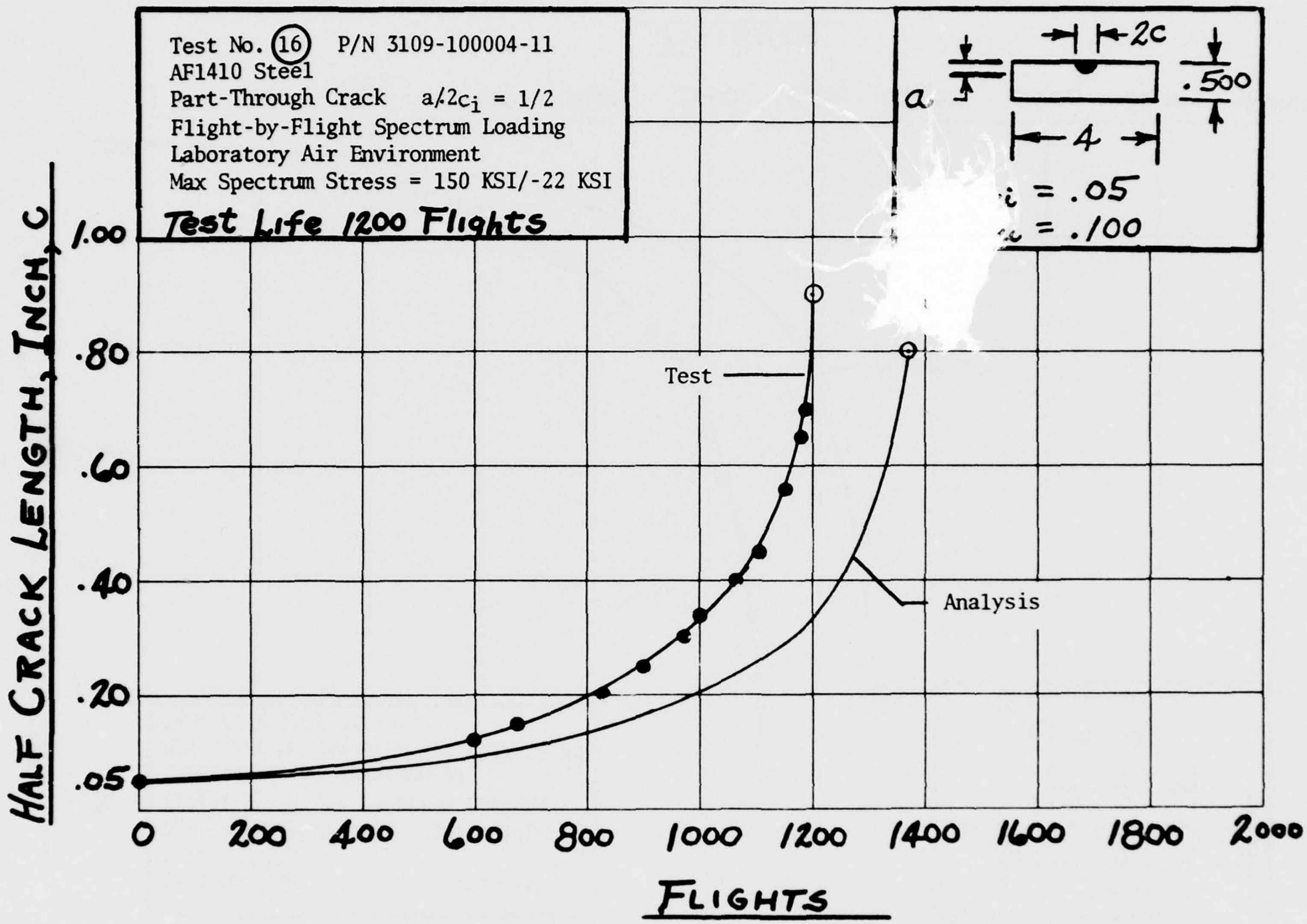


Figure E-6 Fracture Mechanics Crack Growth Test (16)

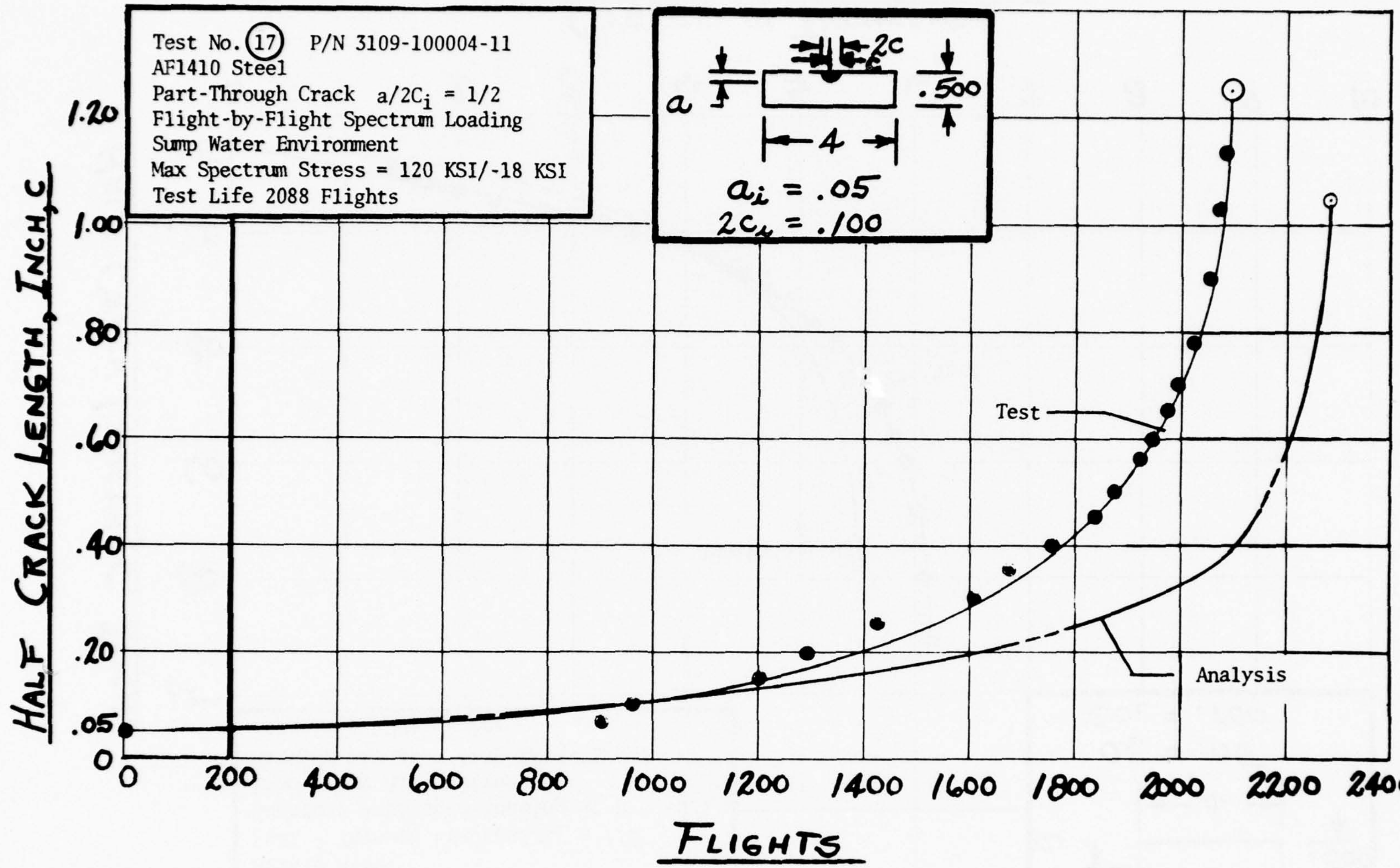


Figure E-7 Fracture Mechanics Crack Growth Test (17)

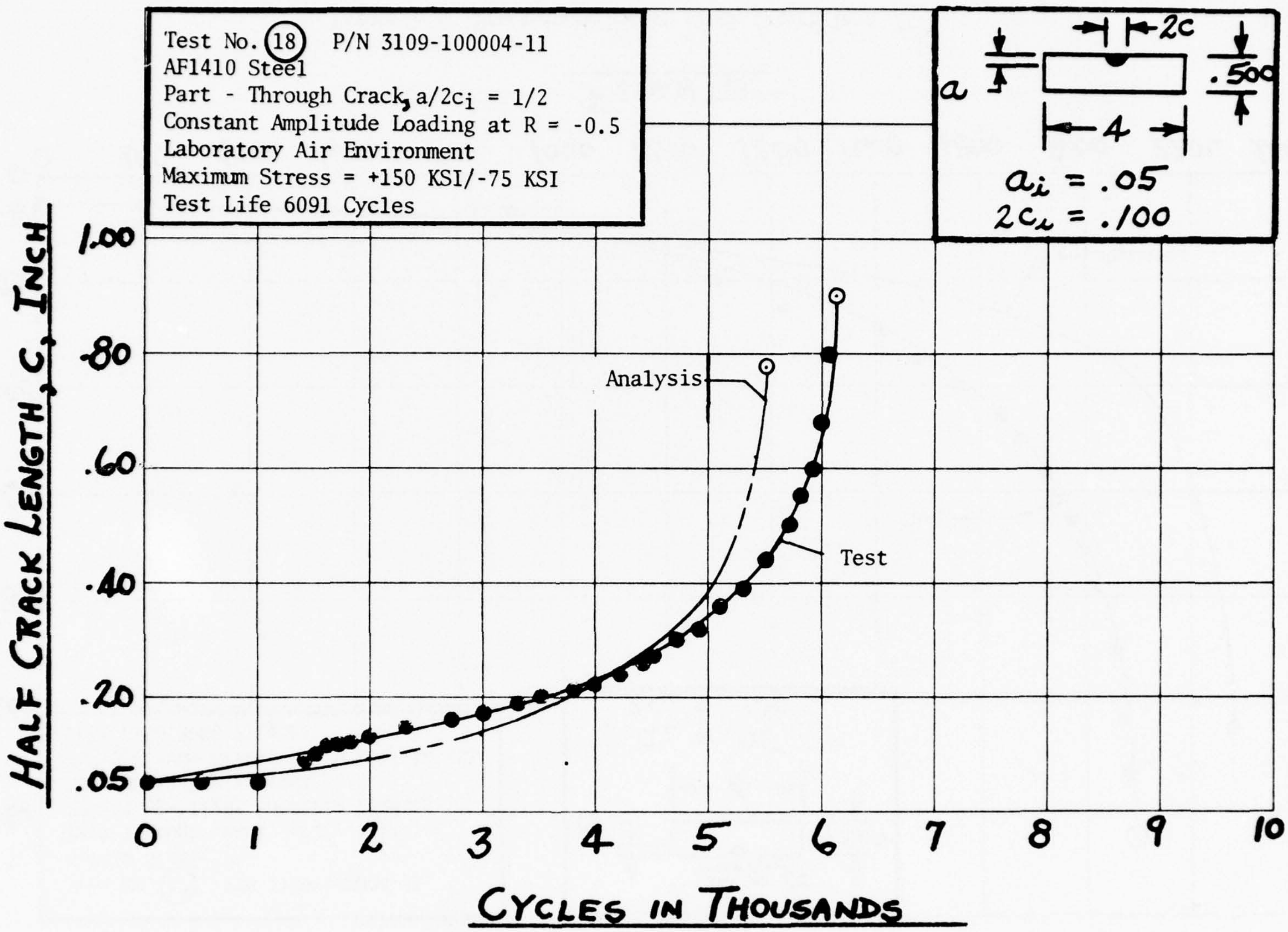


Figure E-8 Fracture Mechanics Crack Growth Test (18)

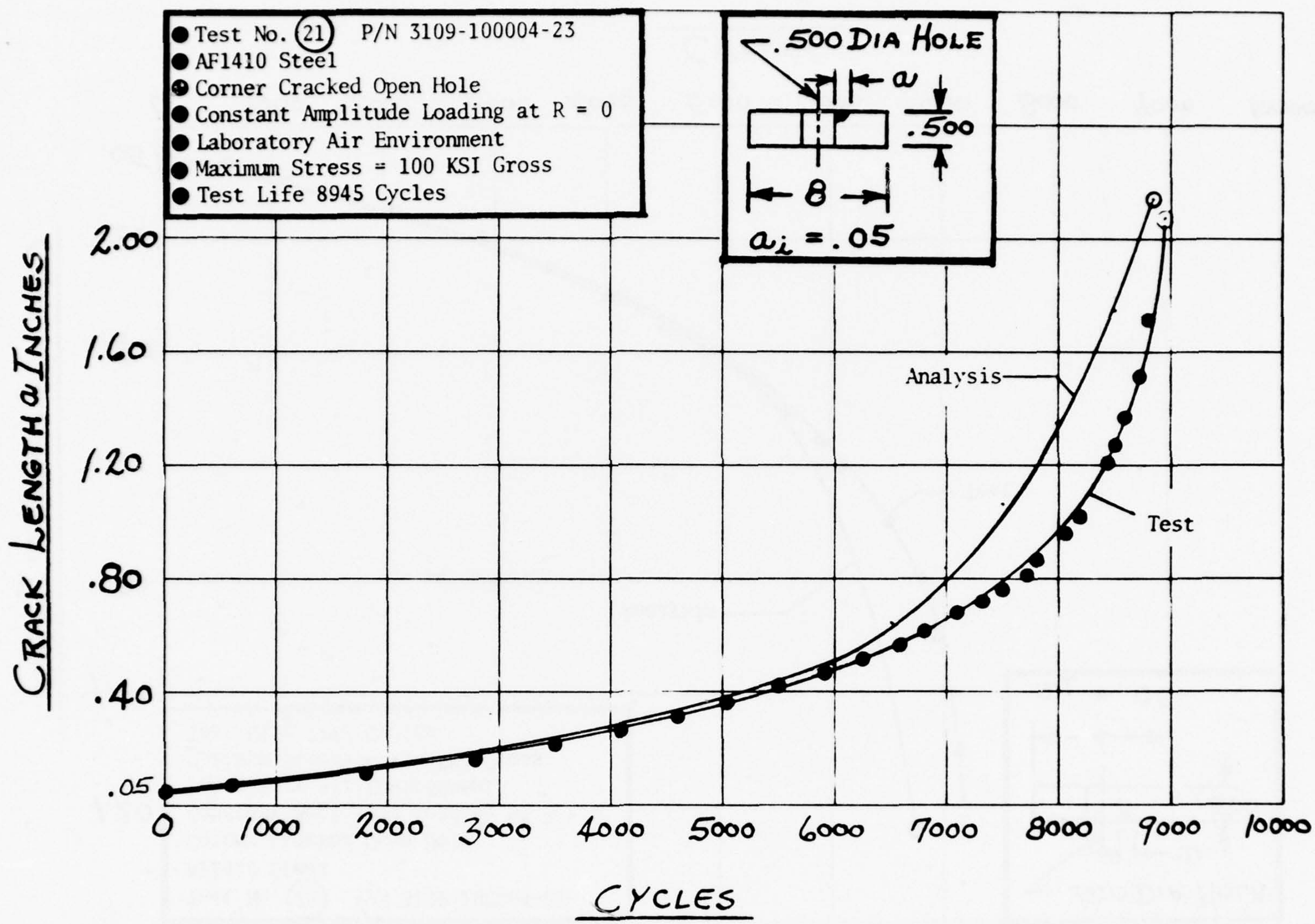


Figure E-9 Fracture Mechanics Crack Growth Test 21

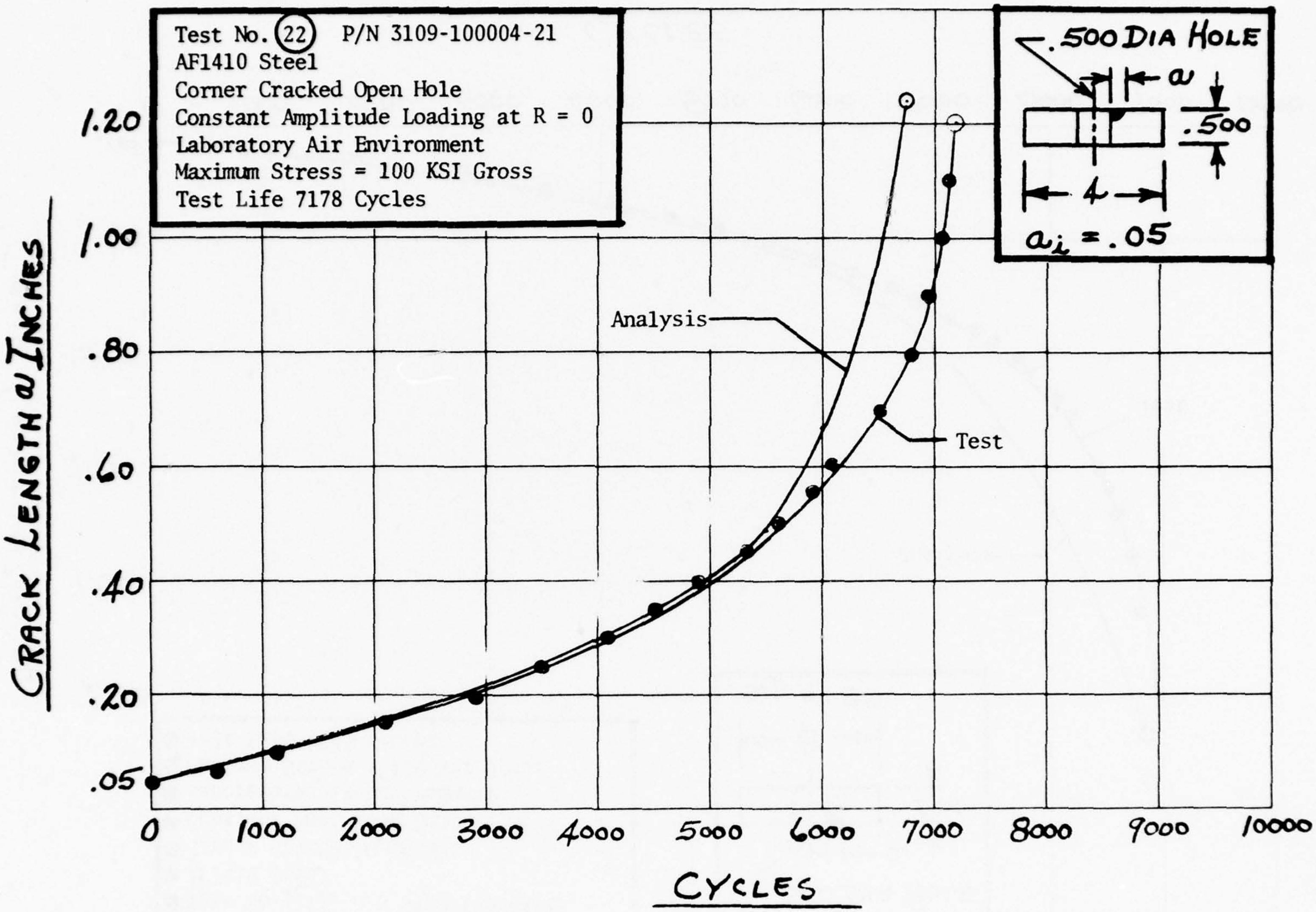


Figure E-10. Fracture Mechanics Crack Growth Test 22

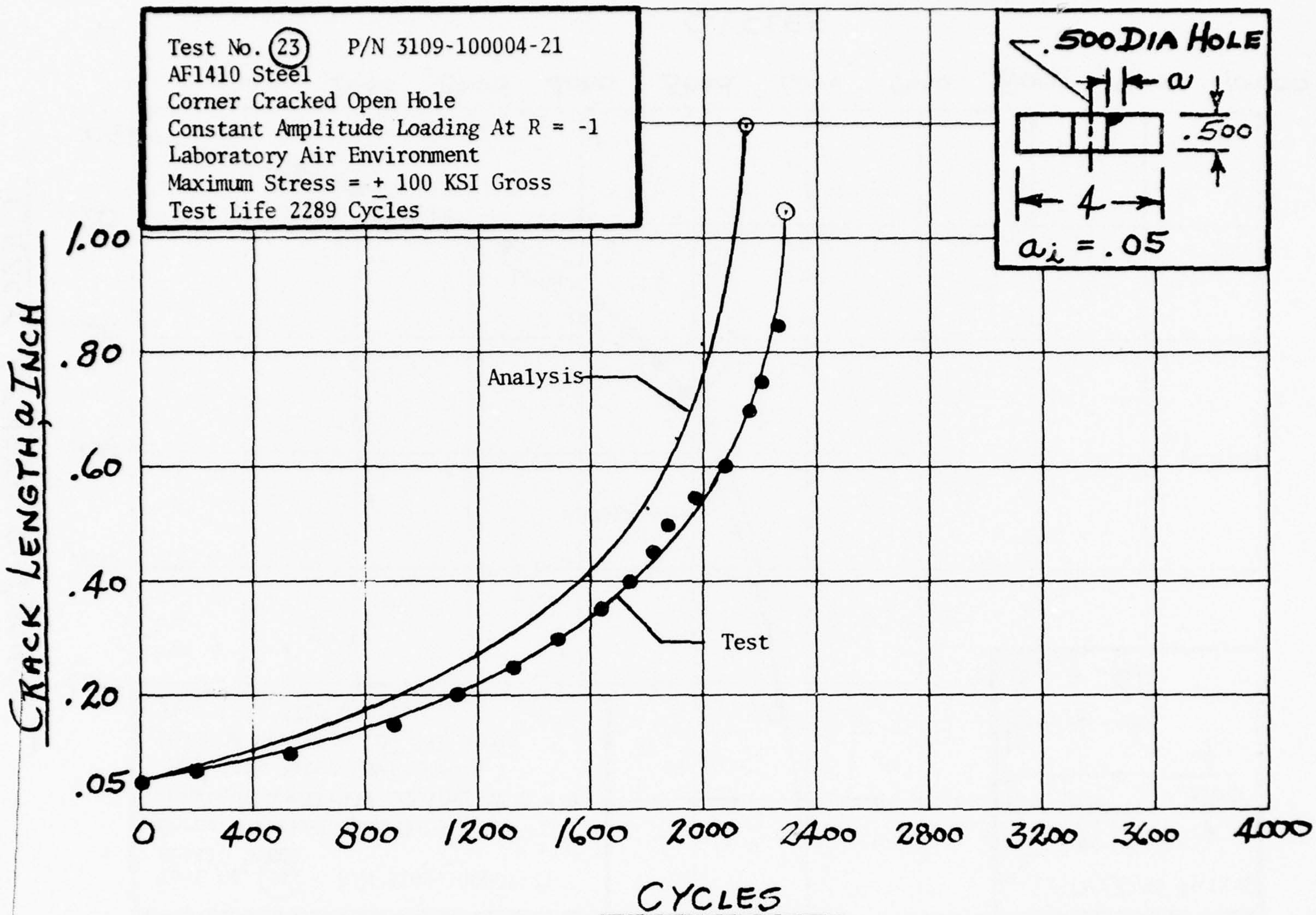


Figure E-11 Fracture Mechanics Crack Growth Test 23

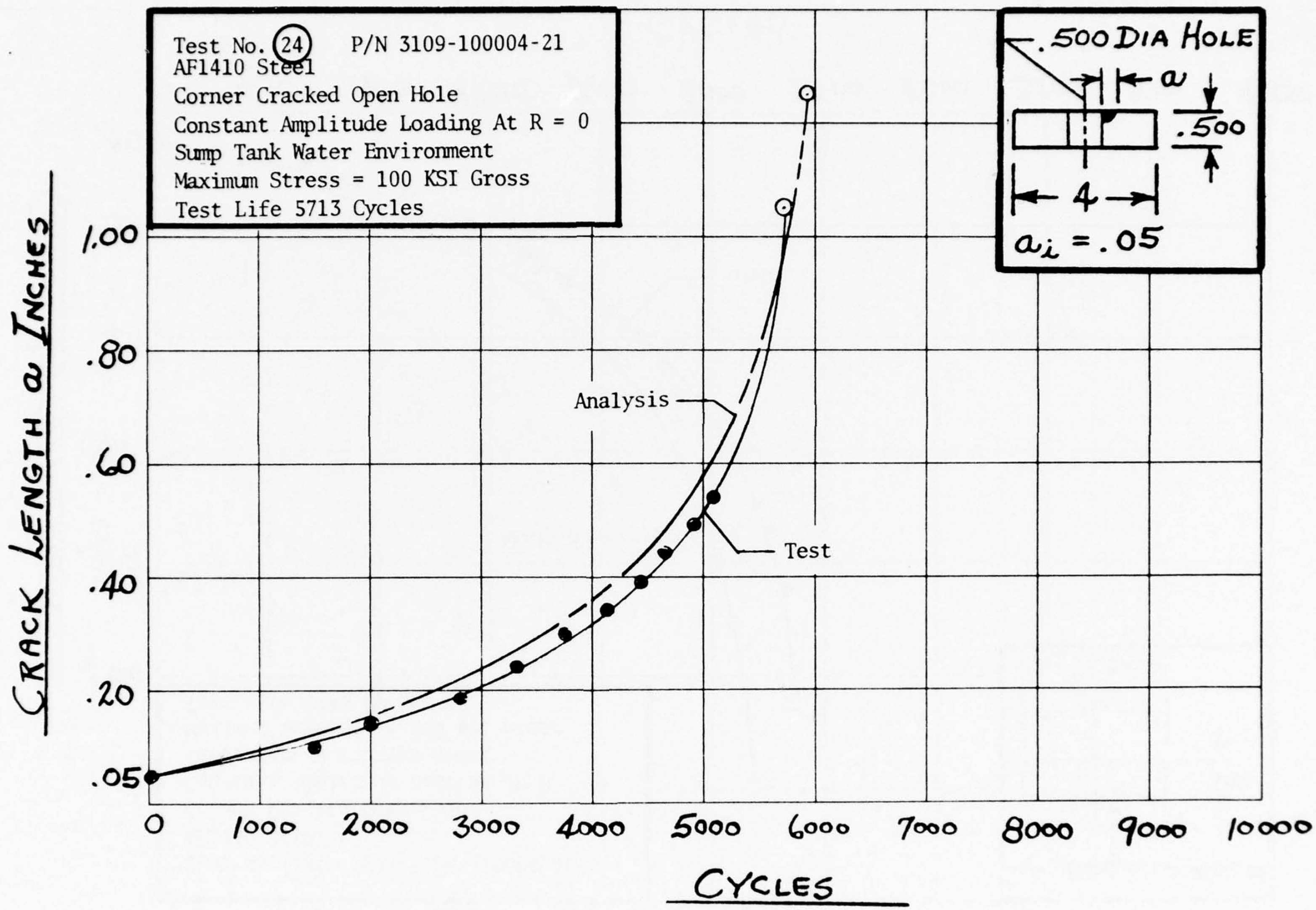


Figure E-12 Fracture Mechanics Crack Growth Test (24)

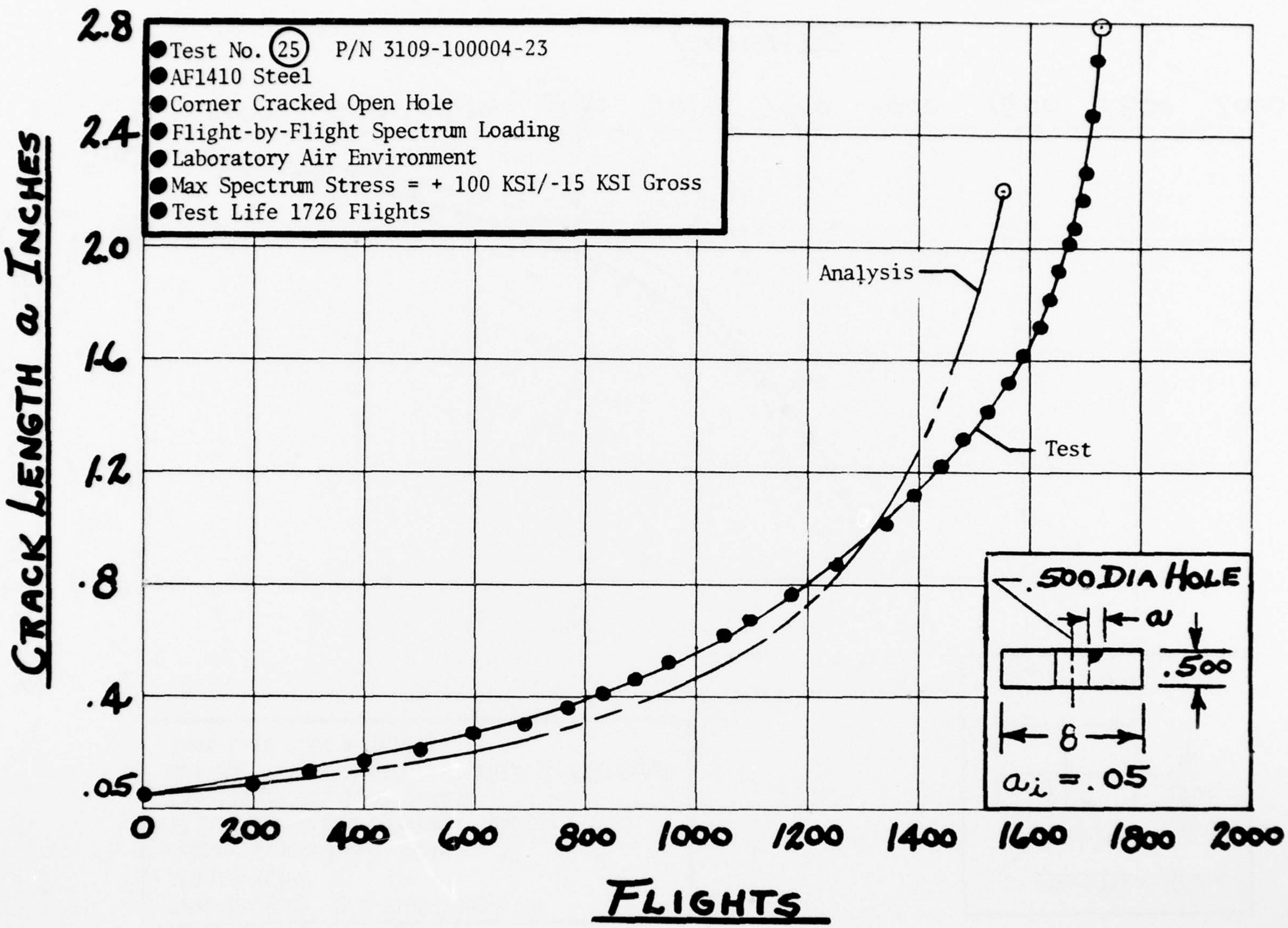


Figure E-13 Fracture Mechanics Crack Growth Test 25

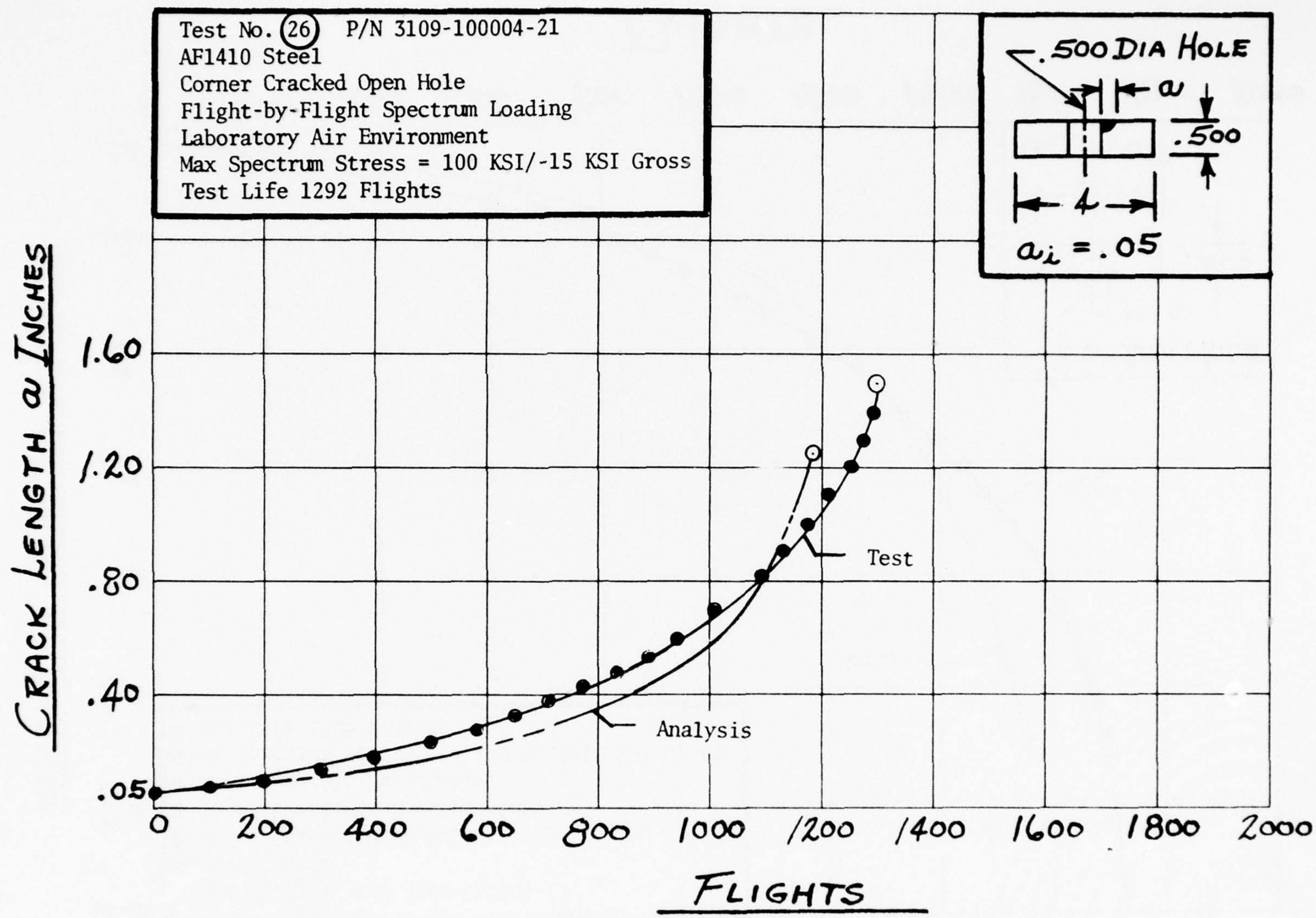


Figure E-14 Fracture Mechanics Crack Growth Test (26)

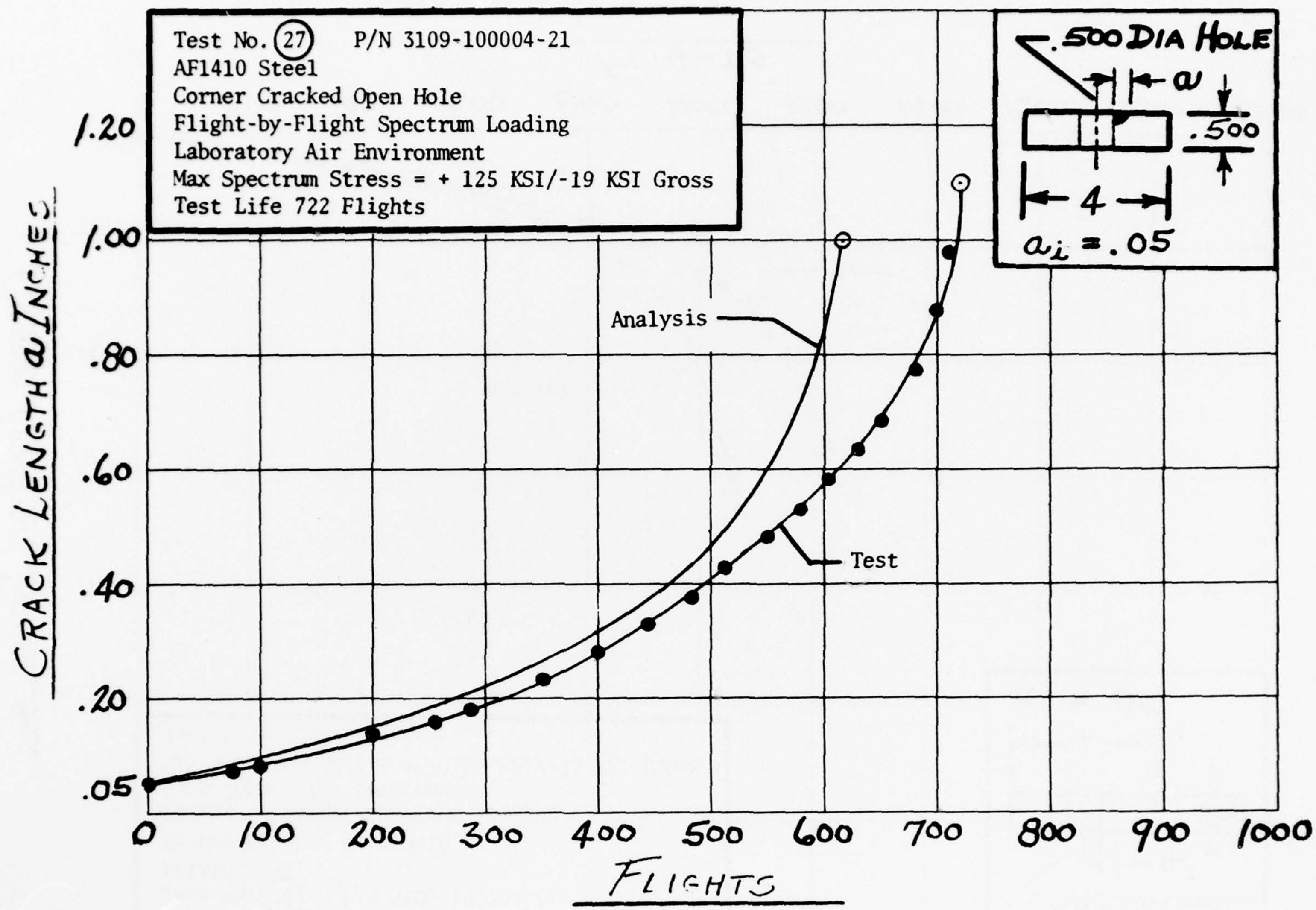


Figure E-15 Fracture Mechanics Crack Growth Test 27

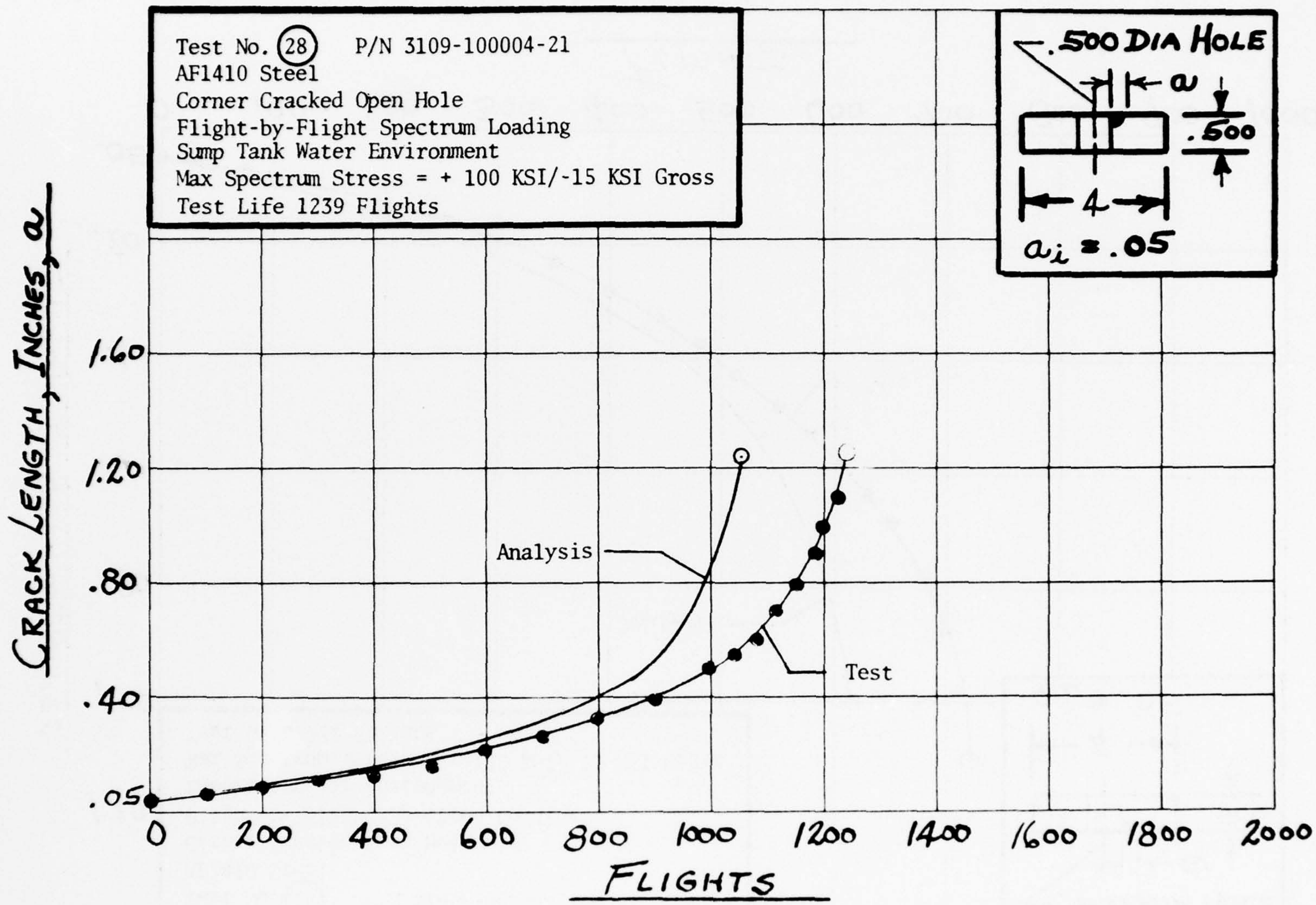


Figure E-16 Fracture Mechanics Crack Growth Test (28)

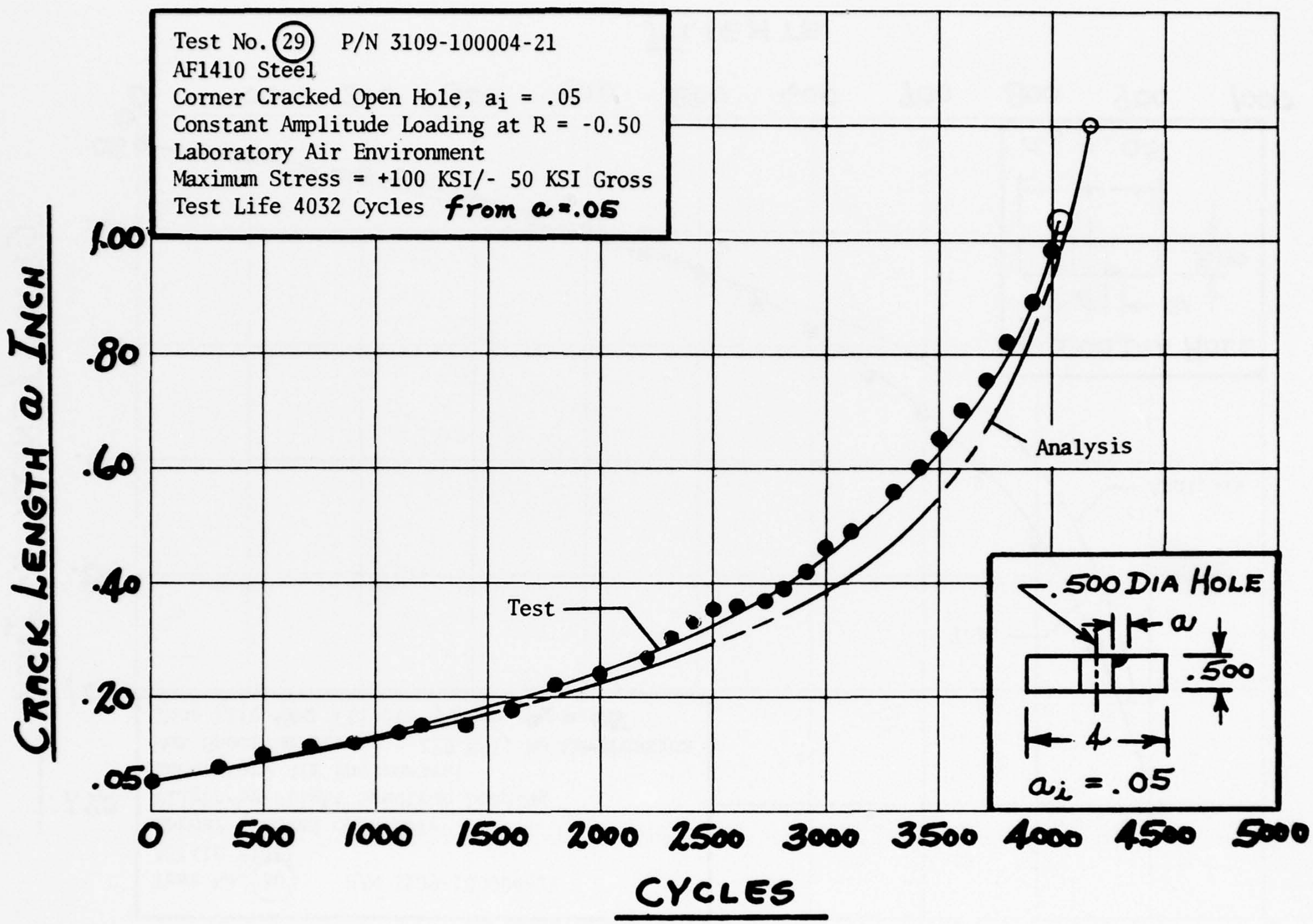


Figure E-17 Fracture Mechanics Crack Growth Test 29

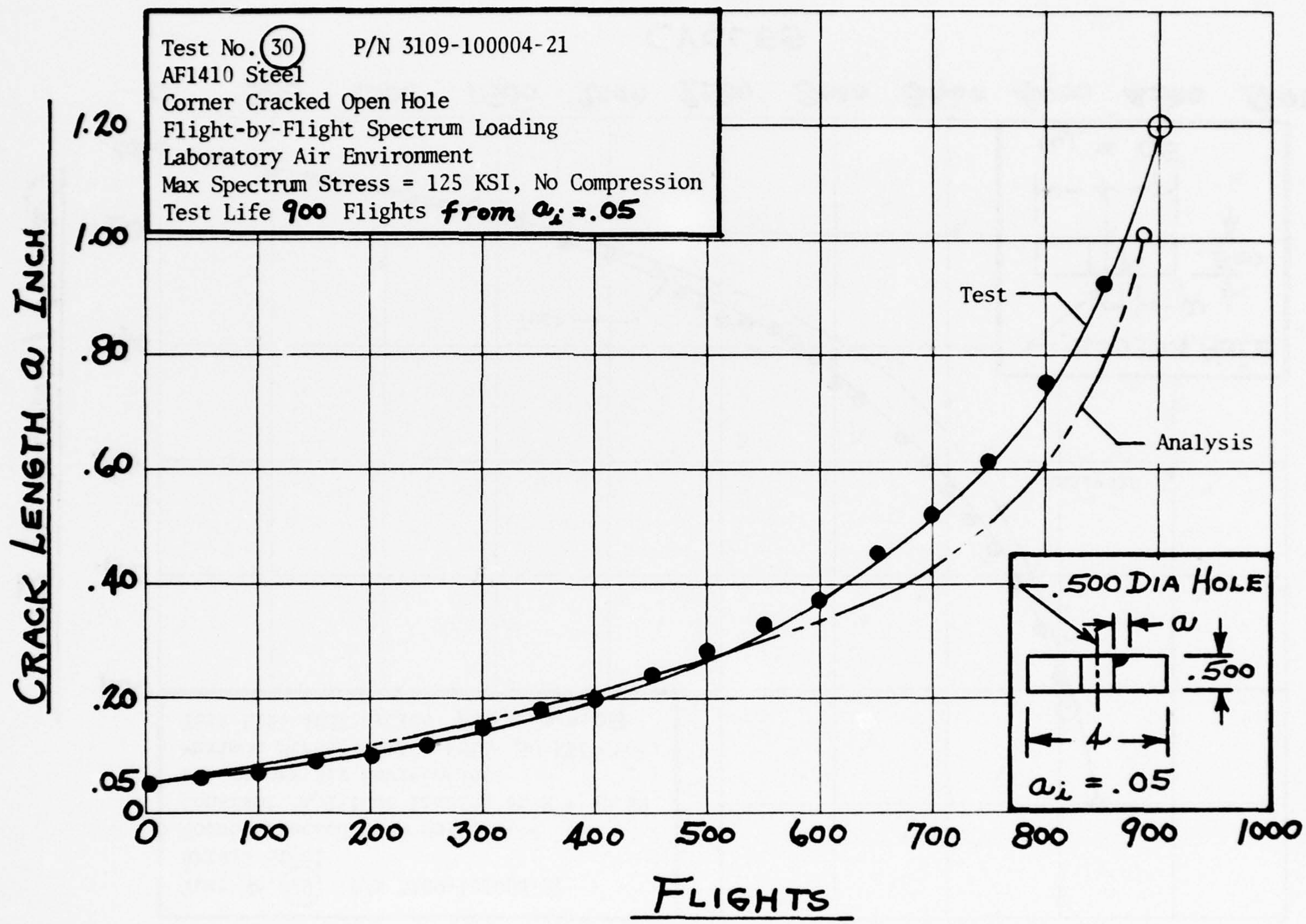


Figure E-26 Fracture Mechanics Crack Growth Test (30)

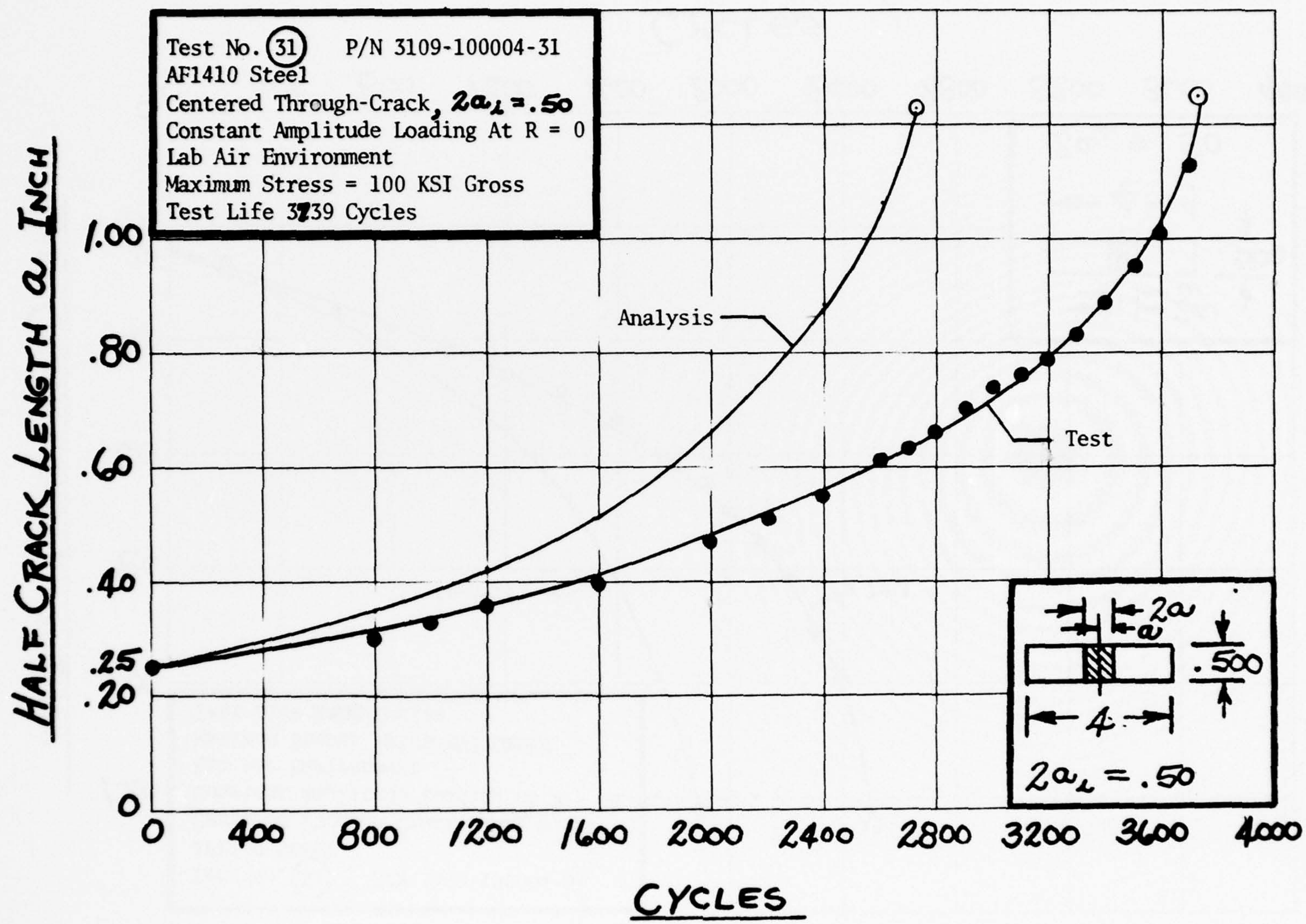


Figure E-18 Fracture Mechanics Crack Growth Test (31)

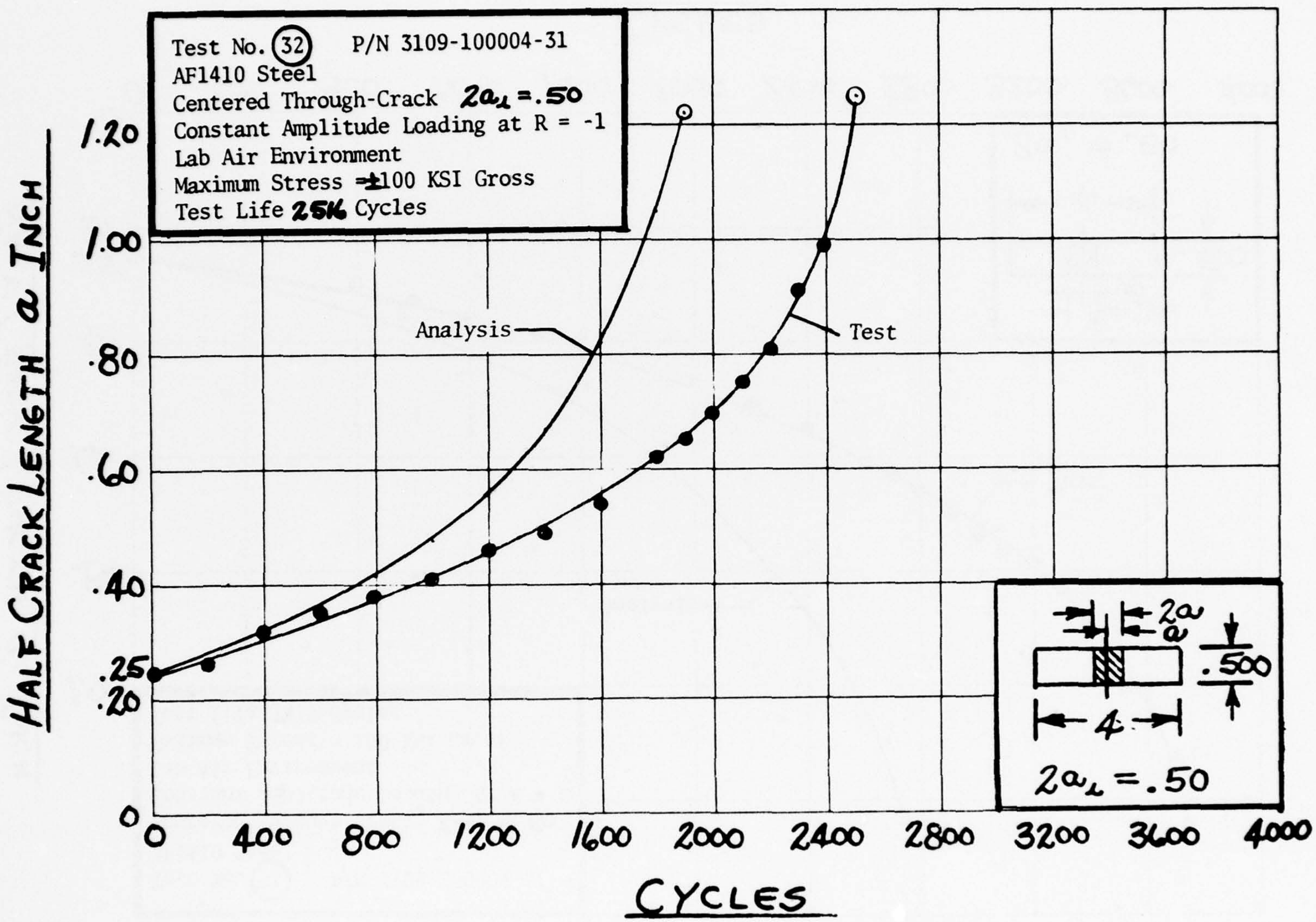


Figure E-19 Fracture Mechanics Crack Growth Test 32

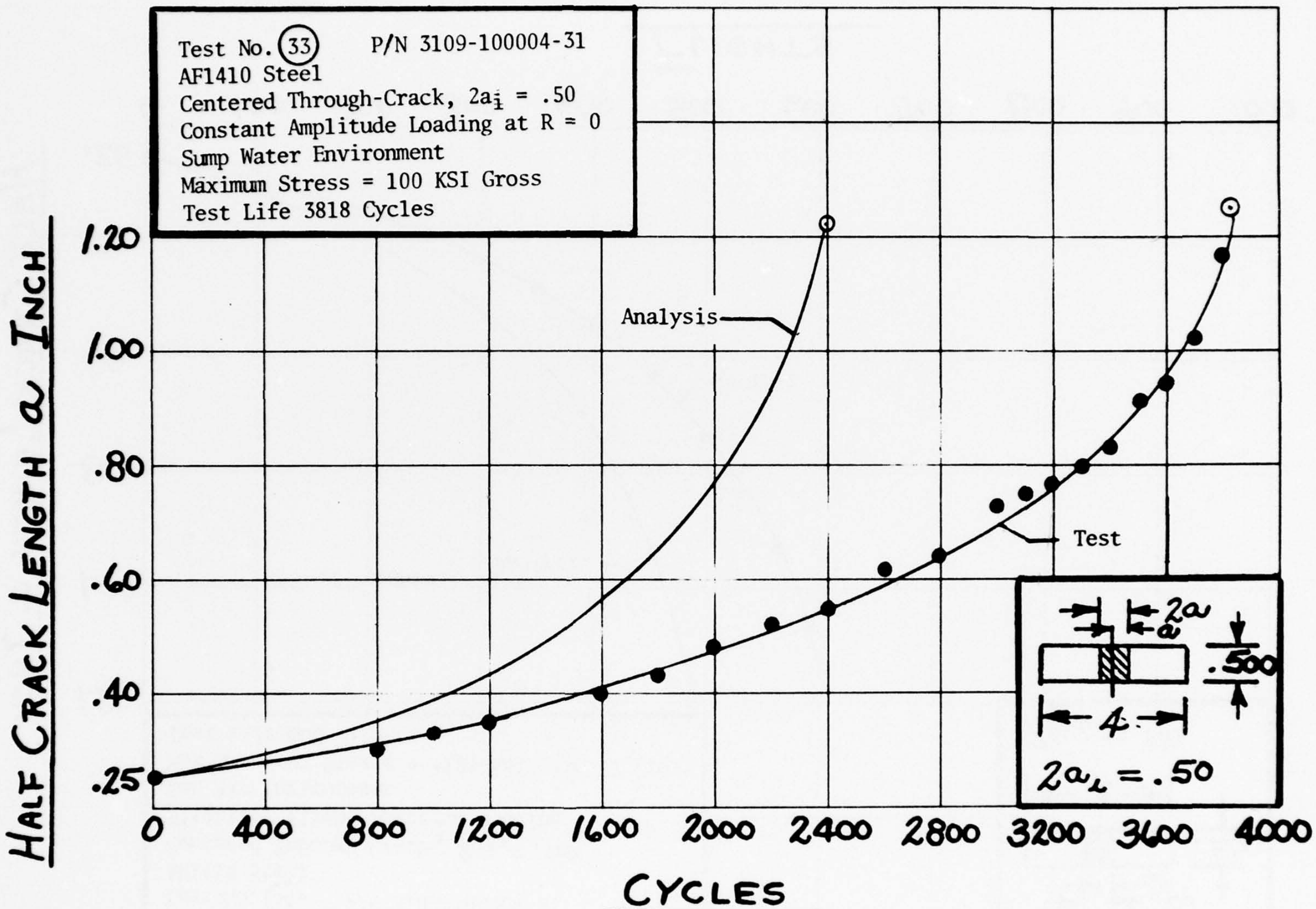


Figure E-20 Fracture Mechanics Crack Growth Test (33)

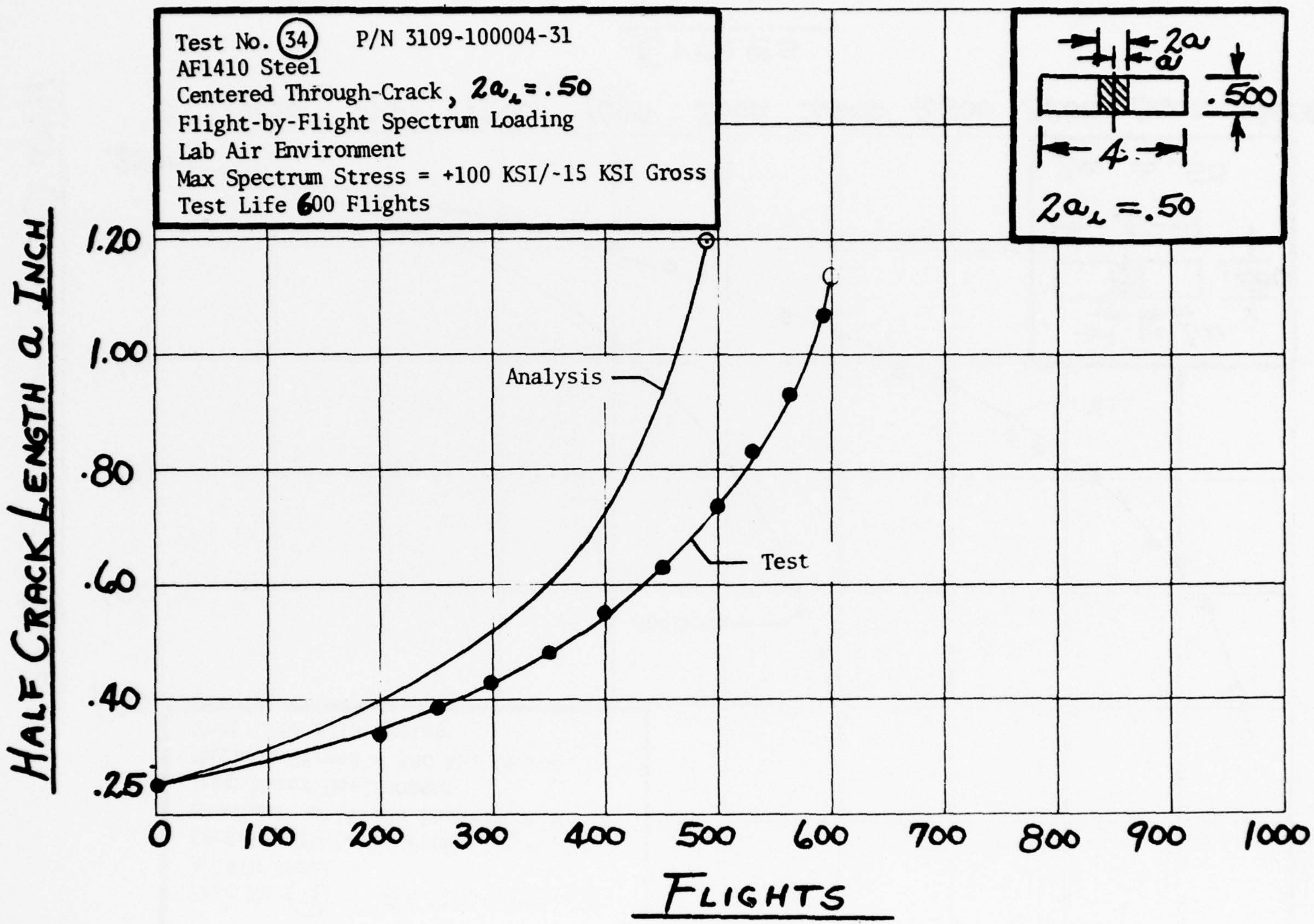


Figure E-21 Fracture Mechanics Crack Growth Test (34)

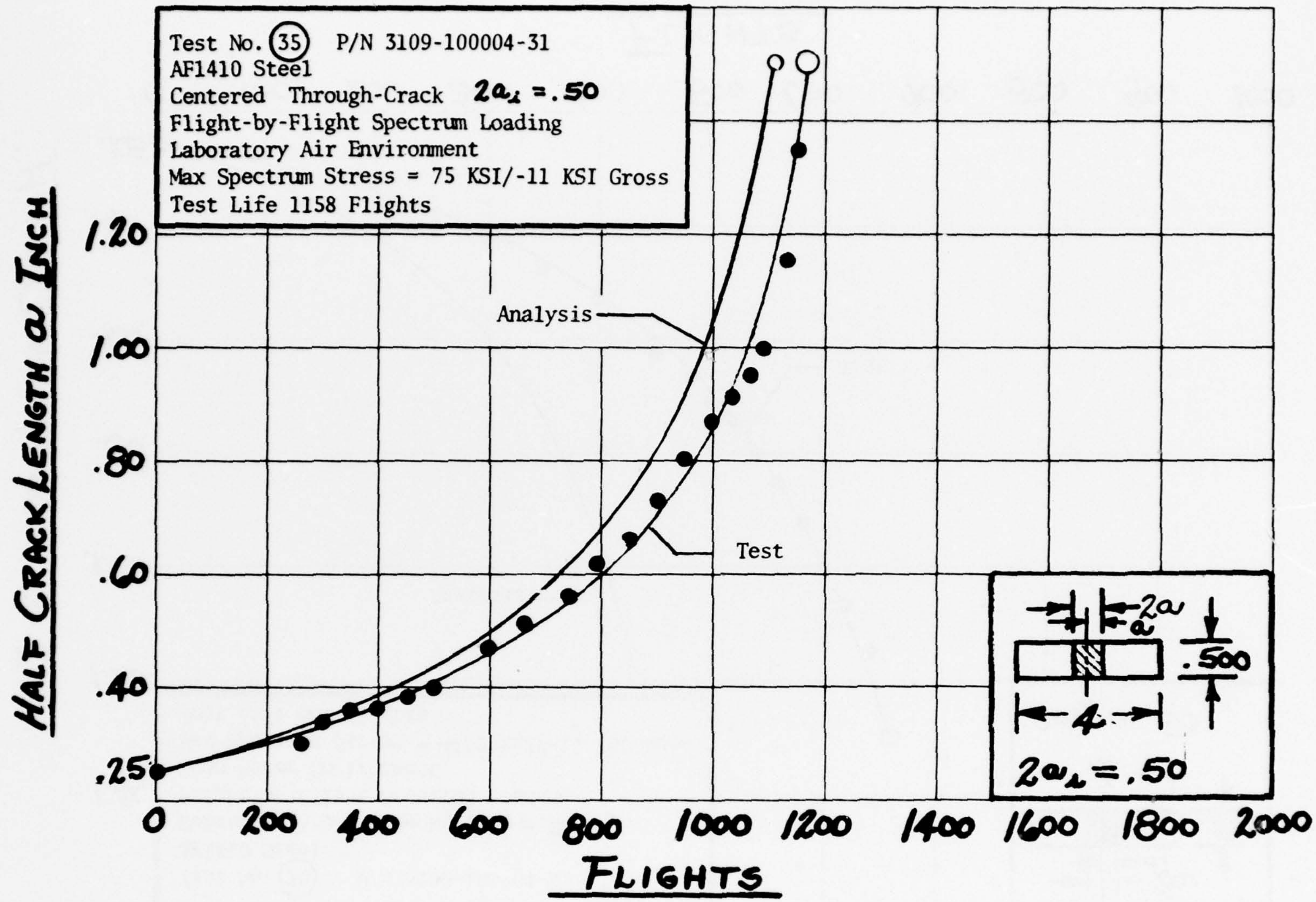


Figure E-22 Fracture Mechanics Crack Growth Test 35

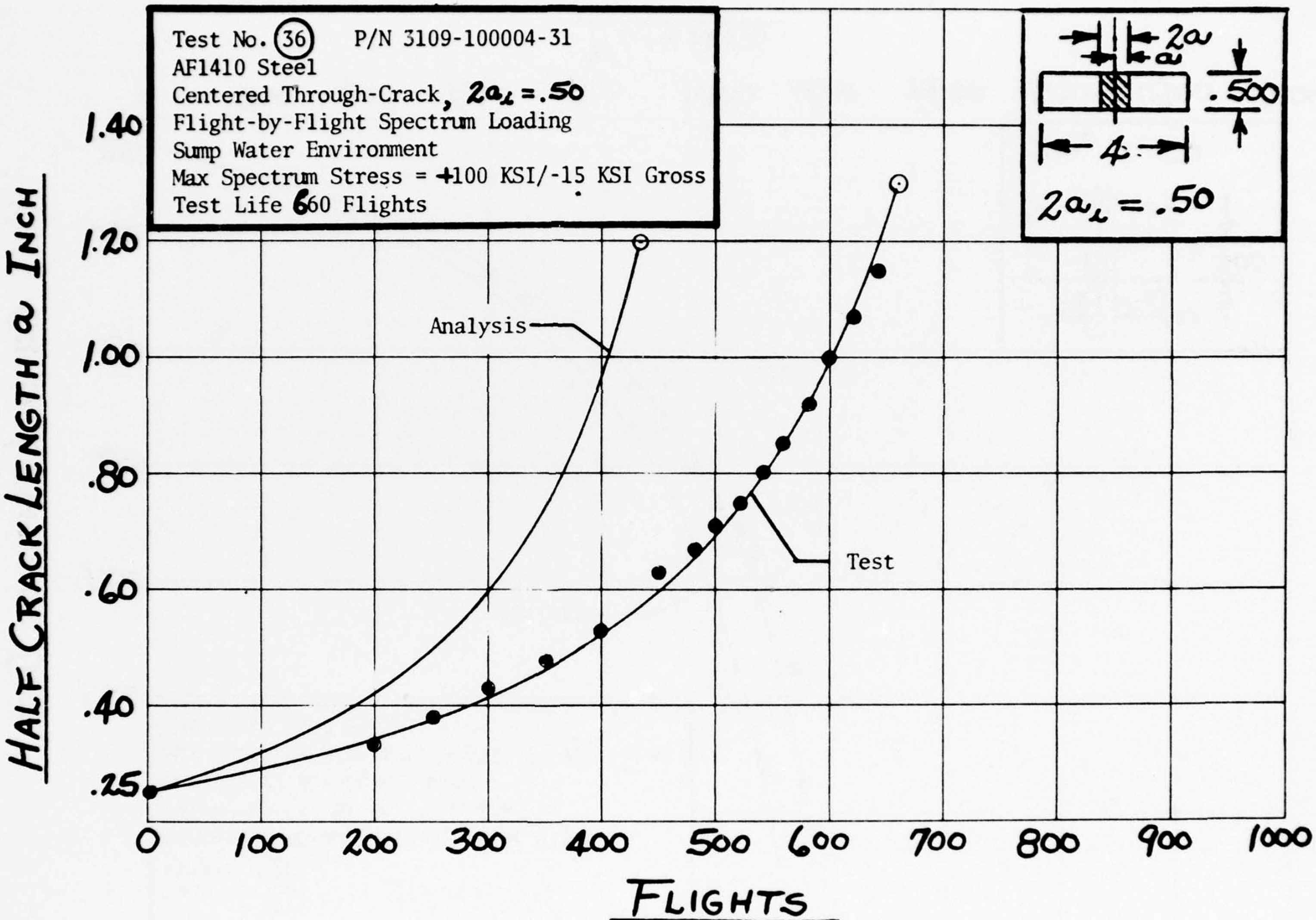


Figure E-23 Fracture Mechanics Crack Growth Test 36

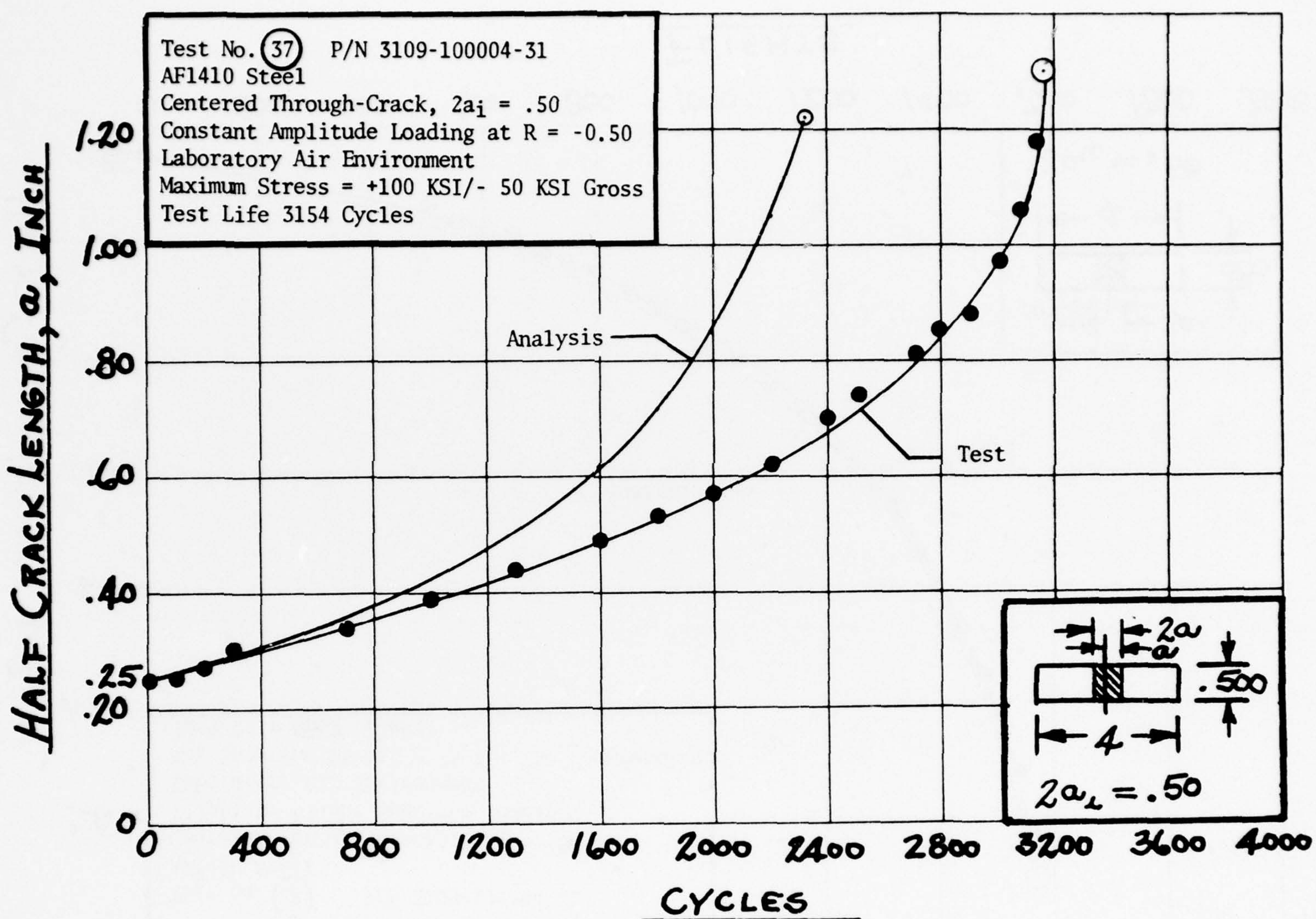


Figure E-24 Fracture Mechanics Crack Growth Test (37)

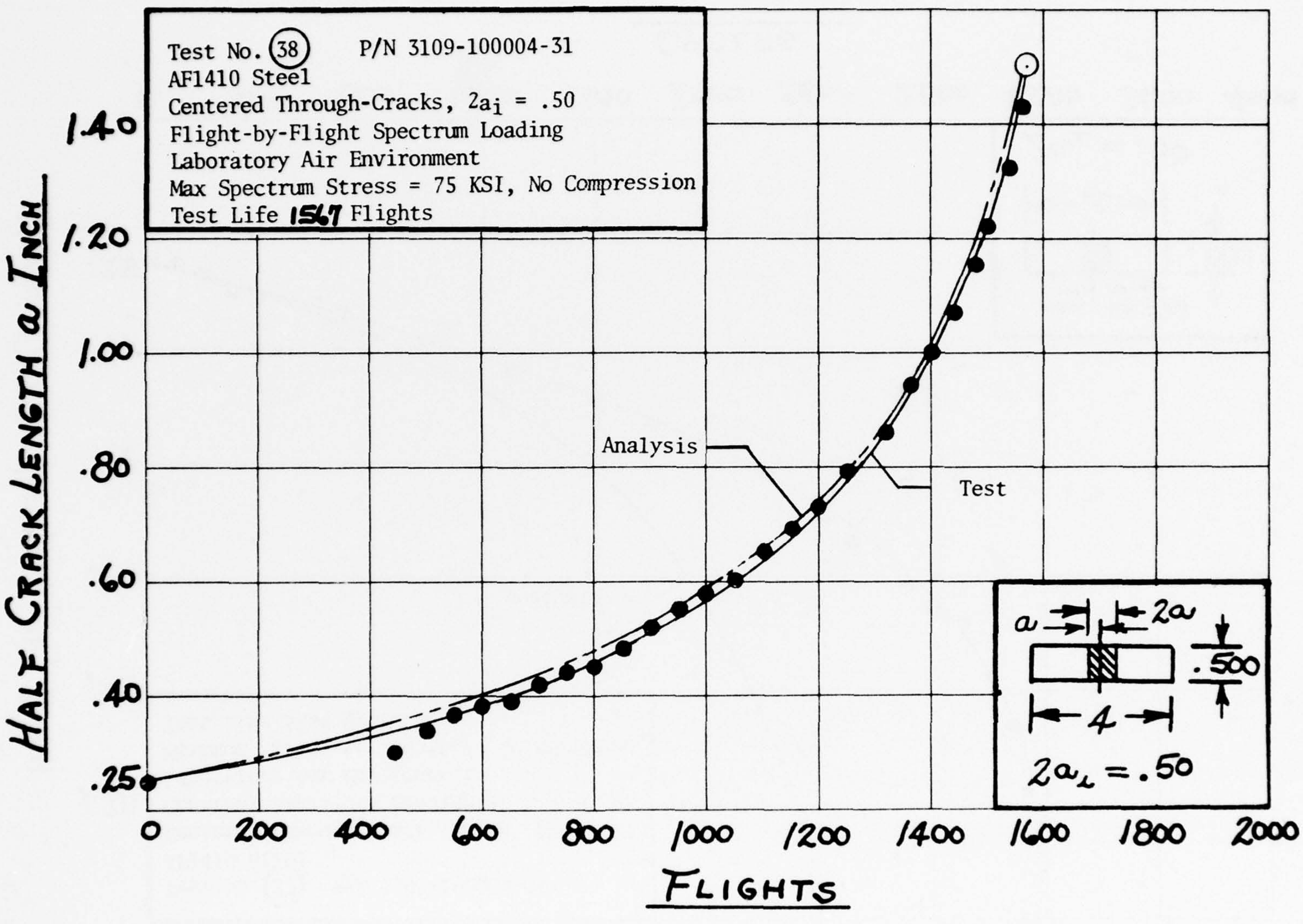
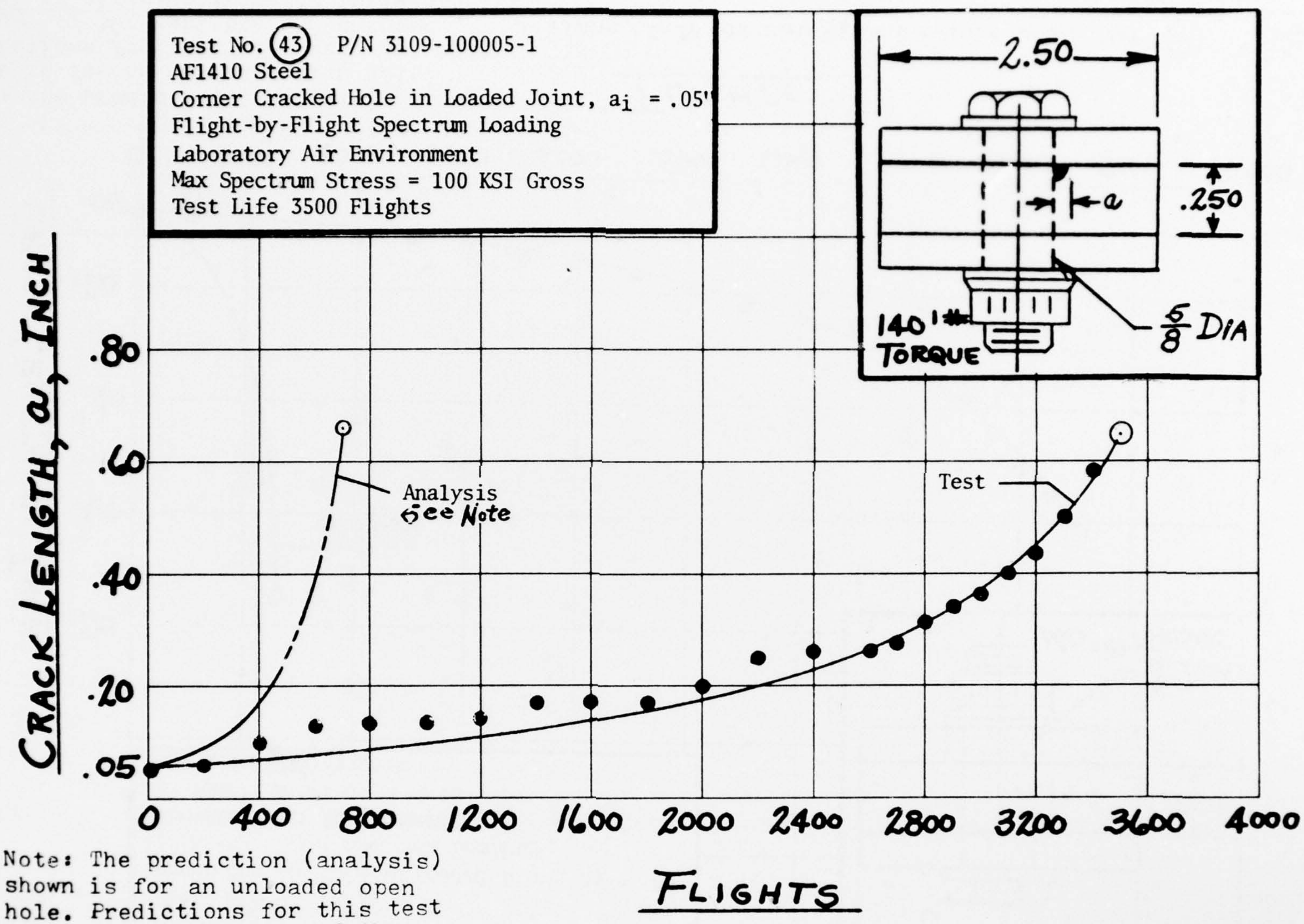
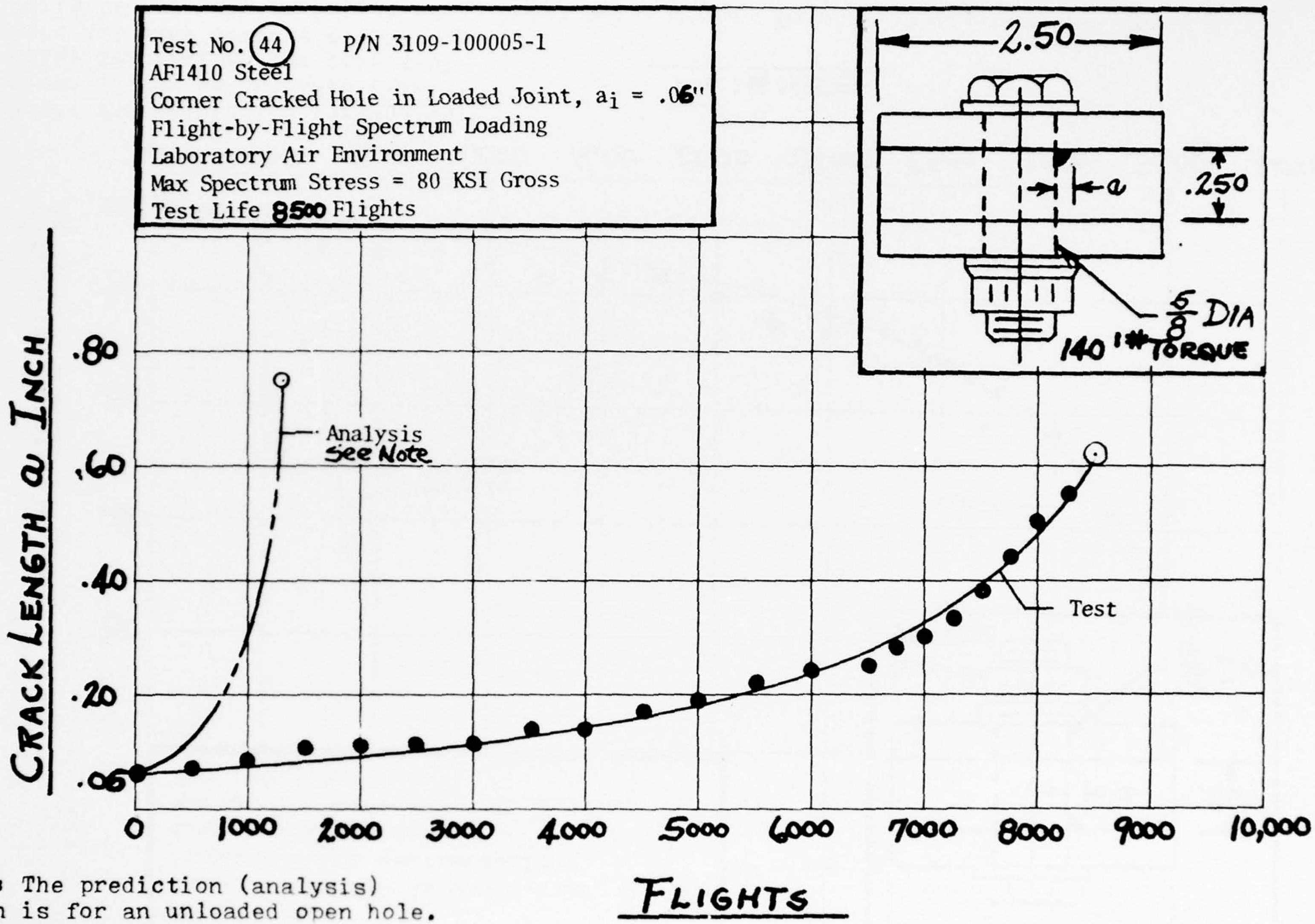


Figure E-25 Fracture Mechanics Crack Growth Test 38



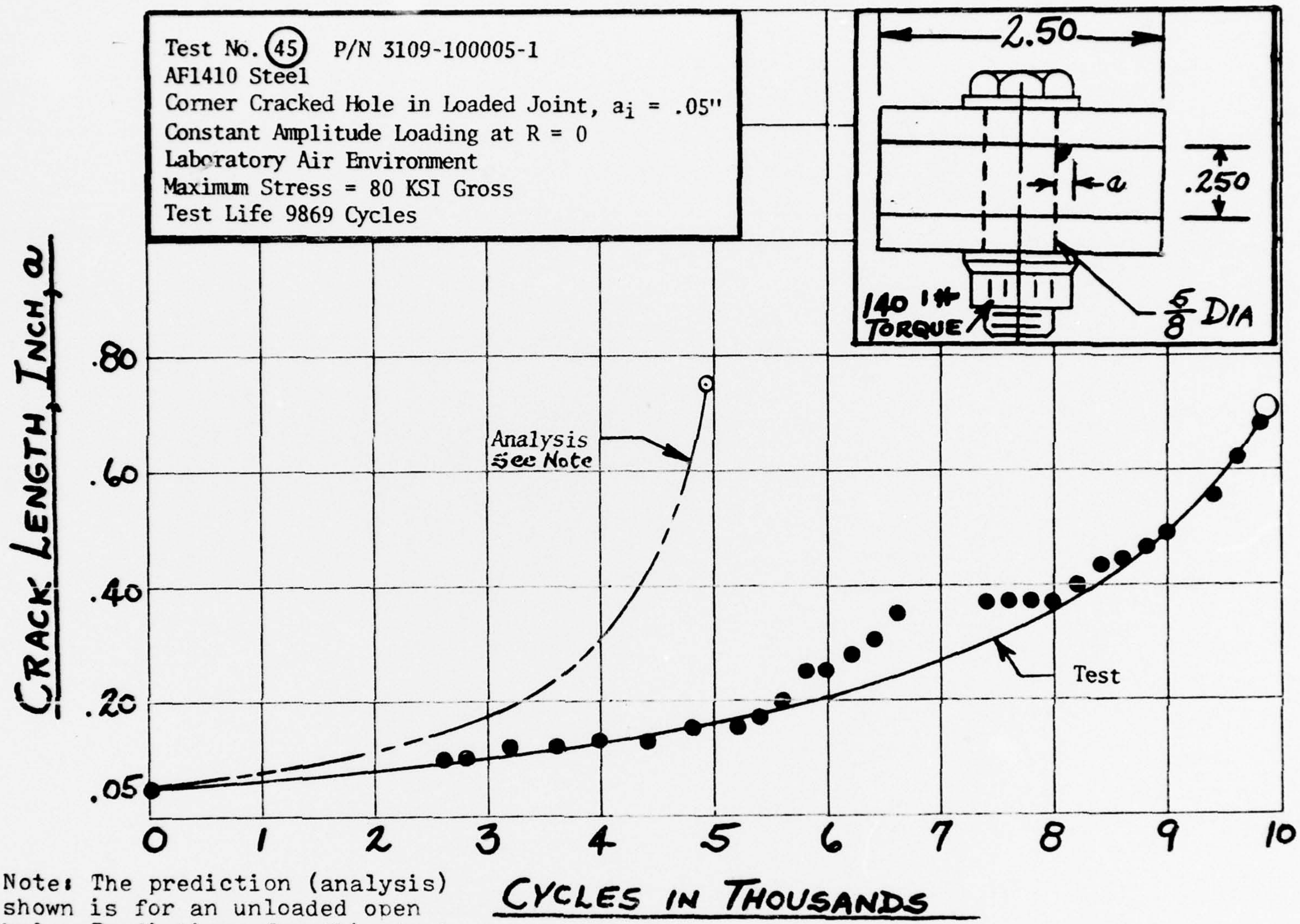
Note: The prediction (analysis) shown is for an unloaded open hole. Predictions for this test were not made because of the variable and unknown impact of clamp-up from the torqued bolt. See discussion in text.

Figure E-27 Fracture Mechanics Crack Growth Test (43)



Note: The prediction (analysis) shown is for an unloaded open hole. Predictions for this test were not made because of the variable and unknown impact of clamp-up from the torqued bolt. See discussion in text.

Figure E-28 Fracture Mechanics Crack Growth Test 44



Note: The prediction (analysis) shown is for an unloaded open hole. Predictions for this test were not made because of the variable and unknown impact of clamp-up from the torqued bolt. See discussion in text.

Figure E-29 Fracture Mechanics Crack Growth Test 45

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